ERDC/CERL TR-17-45

US Army Corps of Engineers®
Engineer Research and Development Center

ERDC
INNOVATIVE SOLUTIONS for a safer, better world

Installation Technology Transition Program

Demonstration of Thermoplastic Composite I-Beam Design Bridge at Camp Mackall, NC

Final Report on Projects FY08-16 and FY09-31

Richard G. Lampo, Thomas J. Nosker, George Nagle, Sarah B. Nemeth, Karl Palutke, and Lawrence Clark

December 2017

Construction Engineering Research Laboratory

Installation Technology
Transition Program

ERDC/CERL TR-17-45
December 2017

Demonstration of Thermoplastic Composite I-Beam Design Bridge at Camp Mackall, NC

Final Report on Projects FY08-16 and FY09-31

Richard G. Lampo and Sarah B. Nemeth

Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
2902 Newmark Drive
PO Box 9005
Champaign, IL 61826-9005

Thomas J. Nosker

Rutgers University
Dept. of Materials Science and Engineering
607 Taylor Road
Piscataway, NJ 08854-8065

George Nagle

Axion International, Inc.
180 South Street
New Providence, NJ 07974-1991

Karl Palutke and Lawrence Clark

Mandaree Enterprise Corporation (MEC)
812 Park Drive
Warner Robins, GA 31088

Prepared for Office of the Assistant Chief of Staff for Installation Management
Facilities Branch (DAIM-ODF)
2511 Jefferson Davis Highway
Arlington, VA 22202

Under Installation Technology Transition Program (ITTP) Project FY08-16, "Innovative Recycled-Plastic I-Beam Bridge for Vehicular Traffic" and Project FY09-31, "Phase II, Load Testing and Tech Transfer for Design for Bridges on Military Installations for Military Vehicles."

Abstract

Bridges are essential to many military installations, especially in remote training areas. Like many of our nation's infrastructure bridges, U.S. Army bridges are in critical need of maintenance and repair due to the combination of wear and tear and material degradation, especially the hundreds of wood timber bridges. Repair or replacement represents a major cost to the Army that could be minimized by using cost-competitive, longer-lasting bridges. This effort determined that the innovative use of thermoplastic materials was successful in engineering and constructing a new bridge design that could safely carry the same or greater loads, be virtually maintenance-free, and be cost competitive on a first-cost basis when compared to wood timber bridges. Both the initial load testing and long-term monitoring as well as the life-cycle economic analysis for this project validated the beneficial use of the innovative thermoplastic materials and I-beam design. Moreover, this work is the first recorded effort to construct and demonstrate that a thermoplastic composite bridge of any type can bear the load of a 71-ton (64 Mg) Abrams tank. The results show that the design and materials achieved and surpassed their objectives, and they are recommended to be adopted on a widespread basis.

Contents

Figures and Tables

Figures

Tables

Preface

This study was conducted for the Office of the U.S. Army Assistant Chief of Staff for Installation Management (OACSIM) under the Installation Technology Transition Program (ITTP) Projects FY08-16, “Innovative Recycled-Plastic I-Beam Bridge for Vehicular Traffic” and FY09-31, “Phase II, Load Testing and Tech Transfer for Design for Bridges on Military Installations for Military Vehicles.” The OACSIM technical monitor was Mr. Phillip R. Columbus, DAIM-ODF. Mr. Michael Dean was the Bridge Program Manager at OASCIM, and Mr. Ali Achmar was the Bridge Program Manager at Headquarters, Installation Management Command (IMCOM). The ITTP Program Manager was Ms. Kelly (Dilks) Moon.

The work was performed by the Engineering and Materials Branch (CEERD-CFM), Facilities Division (CF), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL. At the time of publication, Ms. Vicki L. Van Blaricum was Chief, CEERD-CFM; Mr. Donald K. Hicks was Chief, CEERD-CF, and Mr. Kurt Kinnevan, CEERD-CZT, was the Technical Director for Adaptive and Resilient Installations. The Interim Deputy Director of ERDC-CERL was Ms. Michelle Hanson, and the Interim Director was Dr. Kumar Topudurti.

Some work was performed by contractor Mandaree Enterprise Corporation, Warner Robins, GA. In addition, this study and on-site demonstrations would not be possible without others’ direct assistance and support. The authors give special thanks to the following individuals:

- Mr. Steven Sweeney and Mr. James Wilcoski – ERDC-CERL
- Mr. Gregory Bean – Director, DPW, Fort Bragg, NC
- Mr. Darryl Butler – DPW, Fort Bragg, NC
- Mr. George Whitley – DPW, Fort Bragg, NC
- Mr. R.B. Gardner – Facility Manager, Camp Mackall, NC
- Mr. Malcolm McLaren, Dr. George Assis – McLaren Engineering Group, West Nyack, NY

- Mr. James Kerstein – Axion International, New Providence, NJ[1]

The Commander of ERDC was COL Bryan S. Green, and the Director was Dr. David W. Pittman.

[1] All of the thermoplastic composite bridge materials were procured through Axion International as made under a license from Rutgers University. However, the company's license to produce the Rutgers University technology is no longer valid, with the license now held by Sicut Enterprises, Ltd. (www.sicut.co.uk).

Abbreviations

Term	Spellout
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CERL	Construction Engineering Research Laboratory
CPC	Corrosion Prevention Control program
DPW	Department of Public Works
DoD	Department of Defense
ERDC	Engineer Research and Development Center
FRP	Fiber-reinforced polymer
HDPE	high-density polyethylene
HMMWV	High Mobility Multipurpose Wheeled Vehicle
IMCOM	Installation Management Command
ITTP	Installation Technology Transition Program
LVDT	linear variable displacement transducer
NPV	net present value
OACSIM	Office of the U.S. Army Assistant Chief of Staff for Installation Management
OUSD (AT&L)	Office of the Under Secretary of Defense for Acquisitions, Technology and Logistics
R&M	repair and maintenance
TIG	tungsten inert gas
UFC	Unified Facilities Criteria
USEPA	U.S. Environmental Protection Agency
UV	ultraviolet

1 Introduction

1.1 Problem statement

Bridges are an essential part of any military installation, whether they are located on the main installation or in remote training areas. Like many of our nation's infrastructure bridges, Army bridges are in critical need of maintenance and repair due to the combination of (a) wear and tear from traffic load and (b) material degradation from exposure to the elements. The U.S. Army has hundreds of wood timber bridges in its inventory that are in need of major repair or replacement.

Degradation of the wood timber components often leads to reduction in bridge load capacity or closure for safety concerns. Bridge closures or even the need to derate bridges for lower-capacity loads can have a significant negative impact on operations and training activities because such action would require use of alternate routes that add time and fuel costs to the mission. In addition, operation and maintenance budget constraints usually equate to limited repairs on only the most critical structures. Those bridges left unrepaired or not maintained can deteriorate to a point where the needed repair could exceed the cost of replacement.

Wood timber bridges have an average life expectancy of 15–20 yr. This life expectancy can vary depending on the environment, with hot and humid conditions showing life expectancy at the lower end of the scale (due to increased activity by wood-destroying insects or fungi-induced rot). Achieving this overall life expectancy also requires periodic annual maintenance. If maintenance is not performed, life expectancy will be reduced.

If old, deteriorated wood timber bridges are replaced with the same treated wood materials originally used, the degradation and maintenance cycle just begins again. A material system is needed that is resistant to environmental degradation and cost beneficial when compared to traditional treated timbers for wood bridges.

Industry began developing thermoplastic lumber products as alternatives to treated-wood materials, starting in the mid-1990s. Following initial production of thermoplastic products for landscape timbers, park benches,

and picnic tables, these products have been developed into engineered products for structural applications such as piers and bridges (see Section 2.3 for application examples).

The dilemma of repairs and degradation versus limited budgets in the Department of Defense (DoD) and the resulting interest in thermoplastic replacement bridges was highlighted in a U.S. Army Corps of Engineers publication (Finney 2009, 7-8):

> Deteriorated timber bridges are very costly to repair and more often than not, repairs can exceed the cost of replacement. Moreover, the DoD's maintenance and repair budget is not always adequate to renovate deteriorating bridges. And, if the same materials are used, the degradation cycle associated with wood material begins again. The DoD is interested in recycled plastic as a possible replacement for wood timbers at all of its military installations.

This project's overall goal, therefore, was to provide a low-maintenance, affordable structure using recycled thermoplastic materials. Engineers wanted to avoid the use of any wood components which require chemical treatments to fight rot, insect attack, and costly routine maintenance. The DoD is interested in recycled plastic as a possible replacement for wood timbers at all of its military installations.

1.2 Objectives

The overall objectives of this project (which includes Phases I and II under the FY08 and FY09 ITTP projects) were to demonstrate and validate the performance, environmental, and economic benefits of using thermoplastic composite materials and innovative designs as a replacement of treated wood in traditional timber bridge designs.

FY08 funds were made available to build the thermoplastic composite bridge at Fort Bragg, North Carolina. However, insufficient funds were available in FY08 to load test the bridge to its design capacity (that is, to cross an M-1 tank) and to complete the technology transfer documentation. Thus, the FY08 effort was considered Phase I.

The objectives of the FY09 (Phase II) effort were to complete the military load class testing and to complete technology transfer activities in order to make the design and material specifications available throughout the

Army for applications in timber bridges or similar load-bearing structures where chemically treated wood and associated designs are the traditional choices.

The high load limit that become part of the project's objectives occurred at the military installation's request. The original objective of this project was to build and evaluate a thermoplastic composite bridge as a replacement for a conventional wood timber bridge, with an American Association of State Highway and Transportation Officials (AASHTO) load rating of H-20. However, Fort Bragg asked if the new thermoplastic bridge could be designed to cross a 71-ton (64 Mg) M-1 Abrams tank, to accommodate future training requirements in its remote training areas. The research team then proceeded to design, build, and test such a bridge. The goal was to provide a bridge that achieved the required load capacity at a cost that would be competitive to the first cost of a traditional wood timber bridge designed to carry the same load. In addition, the new bridge would achieve durability that would require only minimal maintenance over its 50^{+} years of life expectancy.

1.3 Approach

The bridge was contracted for design by McLaren Engineering Group of West Nyack, New York. Engineers used traditional timber bridge design methodology and incorporated recommended allowable stresses for the thermoplastic composite materials. The following tasks were also completed to meet the above-stated objectives.

- Evaluate the mechanical performance of the bridge.
- Determine cost to complete the bridge and compare that cost to wood structures with the same spans and load ratings.
- Determine other benefits to utilizing this type of construction materials and methods as appropriate.

The original ITTP proposal was to construct a single bridge (T-8518) for the demonstration. However, upon seeing the bridge's design, personnel in the Fort Bragg Directorate of Public Works (DPW) decided that they would like to replace an additional bridge (T-8519) using the same materials and innovative design, so funding was provided to construct a second bridge. The initial load testing of both of these bridges (as part of the ITTP FY09 Proposal) is documented in separate technical reports (Commander and Diaz-Alvarez 2010a, 2010b). While references are made

herein to these tests and their results, further details will be found in the separate reports themselves.

In addition, one of the bridges (T-8518) was selected as a test bed to demonstrate a structural health monitoring system for thermoplastic composite bridges under the Office of the Under Secretary of Defense for Acquisitions, Technology and Logistics (OUSD (AT&L)) Corrosion Prevention and Control (CPC) Program. A report of this CPC project, “Remote Monitoring of a Thermoplastic Composite Bridge at Camp Mackall, NC,” helped to validate long-term performance of these thermoplastic composite bridges (Lampo et al. 2011). To date, the bridge has been performing per the original design, with no indication of material or structural degradation.

A third wooden bridge (T-8520) at Camp Mackall was replaced by using the same thermoplastic composite materials and design as bridges T-8518 and T-8519. The work was performed with funding received by Fort Bragg under the American Recovery and Reinvestment Act of 2009.[2] Some of the lessons learned from the first two bridges were used in this third bridge (e.g., the number and size of the screws used to attach the decking boards and the size of the screws used to attach the side boards on the guard railing system, as described in “Lessons Learned,” Chapter 4).

A Unified Facilities Criteria (UFC), “Fiber Reinforced Polymer (FRP) Composites for Bridge Applications” is currently being developed that will contain design and procurement information to assist in future implementation of the thermoplastic composite bridge designs and assure the expected performance and cost benefits have been validated. This new UFC is expected to be available in 2018.

[2] Nicknamed the “Recovery Act,” Public Law 111-5 was enacted by the 111th U.S. Congress and signed into law by President Barack Obama in February 2009.

2 Background

2.1 Initial applications of plastic lumber

Various types of treated woods are being used in many outdoor applications. Chemically treated yellow pine is typically used in the Eastern United States for decks, and creosote-treated oak is used for railroad ties. Despite the use of chemical treatments or protective coatings, wood eventually rots and/or is attacked by wood-destroying insects and must be replaced. Besides deteriorating in the outdoor elements, wood has natural imperfections such as knots that can also negatively impact its performance.

The substitution of any traditional material with a new material must take into account the required performance for the product and the particular application in mind. At first, plastic lumber was considered only for relatively low-stress applications. As an example, picnic tables and park benches have been successfully produced from plastic lumber and are performing satisfactorily. Some of the earliest designs had the product performing well when new, but sagging over time. Successful applications for unreinforced plastic lumber products have been developed for which concrete or other materials were the traditional material used. Among others, these applications include construction curbs, removable speed bumps, parking lot wheel stops, and bollards. Since then, manufacturers have learned to create designs with lower stress on structural elements and to produce better blends of thermoplastic materials, thus reducing the effects of time-dependent properties on the structure's overall shape.

Many manufacturers found that they could produce decking boards to be fitted atop chemically treated wood frames. This application typically has fairly low values of dead-load stress, and the time-dependent material properties do not play a very important role in most cases. The biggest problem in these applications seems to be the much larger thermal expansion coefficient of plastic lumber as compared to wood. Also, since just the decking boards are plastic lumber, one cannot claim that the whole structure will not biologically decay, or that it is not treated with hazardous materials. To make these claims, the entire structure must be made from plastic and/or polymer composites.

2.2 Material property considerations

According to the USDA Wood Handbook (USDA 2010), pines and oaks typically have moduli of at least 1 million psi (6,900 MPa) and strengths of 2,400 psi (17 MPa) and 3,500 psi (24 MPa), when measured perpendicular and parallel to the grain, respectively. Virgin polyethylene has a modulus of only 160,000 psi (1,100 MPa) and an ultimate strength of 3,500 psi (24 MPa). Polyethylene-based, unreinforced plastic lumber has upper-bound properties similar to virgin polyethylene due to the manufacturing process. Cooling a large cross-section of a semi-crystalline polymer product as part of the manufacturing process leads to voids in the interior cross-section due to thermodynamic and physical chemistry reactions that occur during the cooling process. These voids possess an apparently random size and shape. Impurities in these materials represent material inclusions that also reduce mechanical properties. To reduce the size of the voids, manufacturers have added small amounts of foaming agents without significantly affecting the properties. However, a high level of foaming can significantly reduce stiffness and strength while increasing the thermal expansion coefficient.

The two basic problems that unreinforced plastic lumber has in structural applications to replace wood are (a) lower modulus and (b) an even lower modulus when loaded over a long time (creep). A comparison of mechanical properties of wood along the grain[3] with plastic lumber indicates that the lower modulus of plastic is a much bigger issue than any strength comparison (Figure 1).

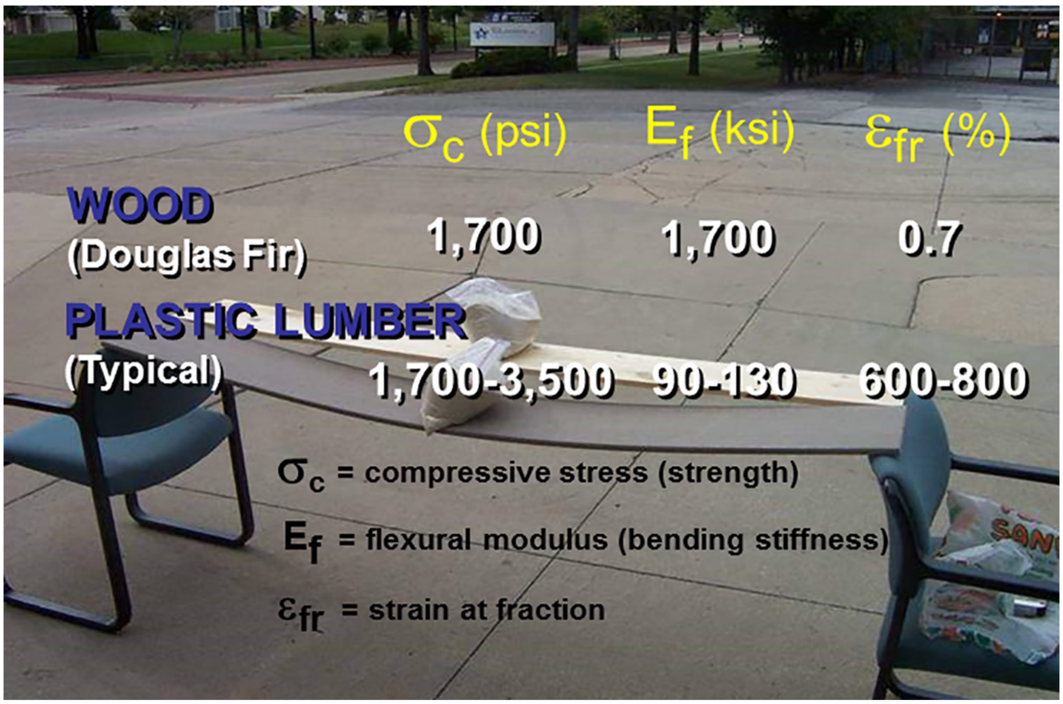
The materials that are typically used in plastic lumber are viscoelastic in terms of their mechanical properties. This means that there is a time-dependence to their mechanical properties. For example, if a structure is loaded to a certain load level and the deflection of that structure is measured right after the load is applied, then the deflection is expected to increase by some value for each increment of time that the load remains applied. To further complicate matters, the deflection will increase more during the first day than it will during the second day. On each subsequent day, the deflection will occur at ever-decreasing rates unless a crack opens

[3] Incidentally, wood is several times less stiff and strong when measured orthogonal to the growth axis as compared to along the growth axis. Most any plastic lumber compares rather favorably in terms of both stiffness and strength in this situation.

up in the material. This effect can be minimized, however, by using designs with lower levels of stress.

The two key advantages of plastic lumber over wood are that it is not subject to degradation (perhaps unless filled with a high percentage of wood material), and it does not leach harmful chemicals into the soil or groundwater.

Figure 1. Comparing strength and modulus of wood (rear) to traditional plastic lumber (front). (Photo credit to Dr. Prabhat Krishnaswamy, Engineering Mechanics Corporation of Columbus.)



2.3 Other demonstrations

In addition to the bridge work reported here, other structurally demanding applications using plastic lumber have been attempted, and all have met with some level of success. These applications have included joists, railroad ties, marine pilings, and vehicular bridge substructures. These applications all required the use of reinforced plastic materials in order to achieve the necessary structural properties at a reasonable cost. The development of accepted ASTM International test methods to evaluate and

compare the properties of plastic lumber has opened up real possibilities to engineer structures with these materials.[4]

2.3.1 Tiffany Street Pier, New York City

The first all-plastic lumber civil structure of major significance was the Tiffany Street Pier located at the end of Tiffany Street in the Bronx in New York City. This roughly 410 ft (125 m) long by 49 ft (15 m) wide recreation pier was designed by the New York City Department of General Services. The structure used recycled plastic for pilings, timber joists, decking, and railings.

2.3.2 Plastic lumber bridge at Fort Leonard Wood

While the Tiffany Street Pier showed that a large all-plastic structure could be built, the structural design of the pier was not very optimal in materials usage. With the help of funding from the U.S. Environmental Protection Agency (USEPA), an existing wood timber bridge at Fort Leonard Wood, Missouri (Figure 2), was selected to demonstrate applications of "structural-grade" plastic lumber in 1998. The 25 ft (7.6 m) long by 26.5 ft (8.1 m) wide plastic lumber bridge sits on the six steel girders that had supported the original wood bridge. Although the bridge is used primarily for pedestrian traffic, the replacement plastic lumber bridge was designed to carry light vehicular traffic. Figure 3 shows an Army High Mobility Multipurpose Wheeled Vehicle (HMMWV) crossing the plastic lumber bridge.

McLaren Engineering Group designed the bridge structure using protocol developed for plastic lumber as part of the ASTM standards development for these products. The safe capacity of the new bridge is more than 30 tons (27 Mg) over the entire structure. Structural-grade plastic lumber were used in the form of 3 x 12 boards that incorporated polystyrene for added stiffness as the main support joists over the steel girders. The decking was also 3 x 12 plastic lumber, but it was made of a standard-grade plastic. In all, products from four different manufacturers were used in the structure. The bridge was constructed with standard woodworking power tools and fasteners.

[4] The relevant ASTM standards are listed in the References section of this report.

The only maintenance or repair completed on the bridge since its construction was replacement of some deck boards at one end of the bridge where the roadway had washed out, causing a cantilever effect that the boards could not sustain as vehicles moved on and off the bridge.

Figure 2. Failing wood timbers on wood bridge structure at Fort Leonard Wood, MO.

Figure 3. Failing bridge replaced by the first-known plastic lumber vehicular bridge in the United States,[5] built during summer 1998 at Fort Leonard Wood, MO.

[5] As reported by "Bridge Advances Plastic Lumber Use," *Roads and Bridges Magazine*, October 1998.

Plastic lumber expands and contracts to a greater extent with changes in temperature than does wood or steel. Therefore, design features were incorporated to allow the plastic lumber bridge structure to move differentially relative to the steel members and the bridge abutments during such changes in temperature. These new design features included slotted connections between the plastic lumber joists and the steel girder to which they were attached to accommodate side-to-side movement, and a floating deck at the bridge abutments to accommodate end-to-end movement.

A typical, treated wood bridge structure at the Fort Leonard Wood site would need to be replaced every 15 years, with biannual inspections and maintenance as needed to replace deteriorated boards and loose fasteners. The plastic lumber bridge is expected to last 50 years with minimal maintenance. While the plastic lumber products cost more than double a replacement treated wood bridge, a life-cycle cost analysis showed the plastic lumber bridge would begin to pay for itself in less than 8 years. An added benefit is the fact that the plastic lumber bridge used some 13,000 lb (5.9 Mg) of waste plastics that otherwise were destined for landfills. This amount of plastic is equivalent to approximately 78,000 1 gal (3.8 L), high-density polyethylene (HDPE) milk jugs and 335,000 8 oz (237 mL) molded polystyrene coffee cups. In addition, the bridge will not require any application of protective coatings or preservatives that can emit environmentally damaging volatile organic compounds into the atmosphere.

2.3.3 Arch-truss bridge at Albany, New York

One way that wood structures are designed involves “laminated beams,” where smaller dimensional lumber such as 2x6 or 2x8 are used to make “built-up” beams and arches, resulting in a more efficient and cost-effective use of materials. Therefore, a 30 ft (9 m) span bridge was used as a demonstration project to investigate if reinforced plastic lumber may be used to construct laminated beams and arches.

The arched top chord of the bridge consists of laminated 2x8 curved members, while the bottom chord is a standard dimensional 8x8 glass fiber-reinforced plastic lumber. Although the bridge only needed to be designed for H-10 (10 ton [9 Mg]) emergency vehicular loading, it was designed and tested for H-15 loading (15 ton [13.6 Mg]). As seen in Figure 4, a loaded dump truck weighing almost 32,000 lb (14.5 Mg) was used for

testing the bridge. The maximum deflection was only 1.2 in. (30 mm), which is more than acceptable for such structures. The bridge was designed and built by M. G. McLaren Consulting Engineers in a remote area, and workers used no heavy equipment or specialized construction tools.

Figure 4. Load testing the plastic lumber, arch-truss bridge in Albany, NY.

2.3.4 I-beam bridge at Wharton State Forest, New Jersey

In 2003, another all-plastic lumber bridge was built using I-beam plastic lumber structural members. This bridge, located in the Wharton State Forest, New Jersey, was designed for a Class H-20 rating (20 ton [18.1 Mg]) since it must be able to support a fire truck that might be needed to answer a call within this part of the forest. The I-beam design reduced the construction time and materials needed to build a bridge structure with the same load capacity compared to conventional joist and beam construction. Figure 5 shows this I-beam design bridge under construction.

The design and construction was a collaborative effort between personnel at McLaren Engineering Group, New York, and Rutgers University, New Jersey. While the costs of this bridge were not fully analyzed and documented, this I-beam design appears to be competitive on a first-cost basis with conventional treated wood with life-cycle considerations because of the reduced material used due to (a) the I-beam design and (2) the reduced labor required to complete the bridge due to the prefabricated

interlocking sections. These two savings combine to make the new design even more advantageous to the bridge owners.

Figure 5. I-beam design bridge being constructed at Wharton State Forest, NJ.

2.3.5 High-capacity I-beam design bridge at Camp Mackall, North Carolina

In 2008, a further opportunity presented itself—to demonstrate and validate the performance and benefits of the I-beam design on an Army installation, as part of the CPC and ITTP programs. Both of these military programs focus on validating emerging technologies and processes that show potential cost savings to the Army and the rest of the DoD through the use of more durable and cost-effective materials and processes. Cooperatively, these two programs funded the design, construction, and performance monitoring of an innovative thermoplastic composite bridge to replace an existing, dilapidated wood timber bridge (T-8518) at Camp Mackall (a sub-installation to Fort Bragg), North Carolina. This bridge had a load limit of 4.7 tons (4,300 kg). In addition, funding was provided by the Fort Bragg DPW for a second bridge (T-8519) to be constructed simultaneously with Bridge T-8518. A third bridge, T-8520, was added in fall 2011 using Recovery Act congressional funding received by Fort Bragg.

More details of the design and construction of the Fort Bragg bridges, which are the subject of this report, are available in Chapter 3, “Technical Investigation.”

2.3.6 Other commercial applications for bridges

As described below, other commercially initiated bridge ventures followed the successes of Bridges T-8518, T-8519, and T-8520 at Camp Mackall.

2.3.6.1 Birch Hill Road Bridge in York, Maine

The first thermoplastic bridge constructed in the U.S. highway system was opened in the state of Maine in December 2011. The bridge is located on Birch Hill Road west of York Harbor and replaced the existing concrete culvert as the waterway was widened from 3 ft to 12 ft (0.9 m to 3.6 m). The concrete culvert needed to be replaced because the area of Birch Hill Road often flooded during storms, causing the road to be closed twice during a 4–5 year period.

The two-lane bridge is approximately 26 feet (7.9 m) wide and 14 feet (4.3 m) long. The bridge consists of a single span with curbing, abutment headwalls, and wingwalls (Figure 6). The entire bridge's components—including girders, piles, pier caps, backwalls, and wingwalls—are made of recycled plastics that would otherwise be discarded into landfills.

Dean Lessard, Director of Public Works for the town of York and a professional engineer, has said the following (Axion 2011): "This bridge will be a great addition to our historic, forward thinking and environmental conscience town. Our Board of Selectmen was extremely supportive in utilizing recycled plastic technology to replace the undersized culvert that was prone to causing that section of Birch Hill road to flood. I recommended thermoplastic over other options due to the structure's timber-like appearance and the product's environmental credentials, combined with its durability and minimum maintenance requirements."

Figure 6. Birch Hill Road bridge in York, Maine.

2.3.6.2 Bridge in Scotland

According to the builder, Vertech Composites, a 90 foot (27 m) bridge over the River Tweed in Scotland was the first thermoplastic bridge to be built outside the United States, and it was the longest plastic bridge ever built when installed in 2011 (Figure 7). The bridge's beams are molded of a high-density polyethylene thermoplastic composite made from post-consumer waste. The bridge can support vehicles as heavy as 44 tons (40 Mg), which is heavier than most tractor trailers. Because it is made of plastic, the bridge is expected to have a lifespan of about 50 years. To build the bridge, the Welsh firm of Vertech Composites worked with the Cardiff University School of Engineering and the Rutgers University Advanced Polymer Center (the latter having helped construct Fort Bragg's thermoplastic composite bridges).

The bridge is approximately 12 ft wide x 90 ft long (3.7 m x 27m) and replaces a steel beam and timber deck road bridge that was built in 1888 and is located on a parcel of private property near Edinburgh, Scotland.

Figure 7. Installing a beam on the 90-foot bridge over River Tweed in Scotland (Vertach 2011).

2.3.6.3 Railway bridge at Fort Eustis, Virginia

A different type of opportunity to use thermoplastic composite lumber developed when Fort Eustis advertised to replace two of its wood timber railway bridges that were severely deteriorated. The subject bridges were Bridge #3 at 40 ft (12 m) long and Bridge #7 at 75 ft (22 m) long. Each bridge required a load capacity of 130 tons (118 Mg) and was designed to a Cooper E-60 classification (in railway bridge engineering terms). Competing against traditional treated-wood timber designs, the thermoplastic composite alternative was least expensive on an installed cost basis. One feature that helped keep the cost down was that the main deck sections were partially factory assembled in panels that could be easily put into place (Figure 8 and Figure 9). Figure 10 shows a locomotive being used for a load test on the completed bridge. Test results showed the maximum center span deflection was less than 0.25 in. (6.4 mm). (Kim et al. 2011.)

Figure 8. Factory-assembled deck section panels, prior to being installed.

Figure 9. Factory-assembled panels being installed as the bridge deck.

Figure 10. Locomotive used for load test at Fort Eustis on 21 April 2010.

3 Technical Investigation

3.1 Design and materials

3.1.1 Design

Bridges T-8518, T-8519, and T-8520 were designed by McLaren Engineering Group, using traditional timber bridge design methodology but incorporating slightly lower allowable stresses for the thermoplastic composite materials. Table 1 shows the material properties utilized in the design. Appendix A contains a selection of design drawings for all three bridges.

Table 1. Design values for thermoplastic composite bridge.

Elastic modulus for live load (short duration)	E = 350,000 psi (2,400 MPa)
Ultimate compression parallel to grain*	f ' c = 3,500 psi (24 MPa)
Allowable compression parallel to grain*	f ' c = 1,000 psi (6.89 MPa)
Ultimate flexural strength	F ' b = 2,300 psi (15.9 MPa)
Allowable flexural strength	F ' b = 600 psi (4.1 MPa)
Ultimate shear strength parallel to grain*	F ' v = 1,100 psi (7.58 MPa)
Allowable shear strength parallel to grain*	F ' v = 350 psi (2.4 MPa)
Self-weight	ωp = 0.032 pci (8,686 N/m^3)
Coefficient of thermal expansion	ε = 0.000052/^{o}F (2.88889E-05/^{o}C)
* For the flow-molded thermoplastic composite members, grain is considered to be the direction of material flow in the mold during fabrication.	

The bridge design incorporated heavy-duty I-beam members up to 18 in. (46 cm) high and 18 in. (46 cm) wide (Figure 11 and Appendix A, Figure A7). The piles were made from the same glass fiber-reinforced thermoplastic composite material as the I-beams and decking. Stainless steel and other corrosion-resistant bolts and screw fasteners were used in the bridge construction. Measured end to end, Bridge T-8518 was approximately 38 ft (11.6 m) long, Bridge T-8519 was approximately 46 ft (14 m) long, and Bridge T-8520 was approximately 56 ft (17 m) long. The three bridges are shown in Figure 12.

Figure 11. Cross-section design detail for innovative thermoplastic composite I-beam girder and pile cap.

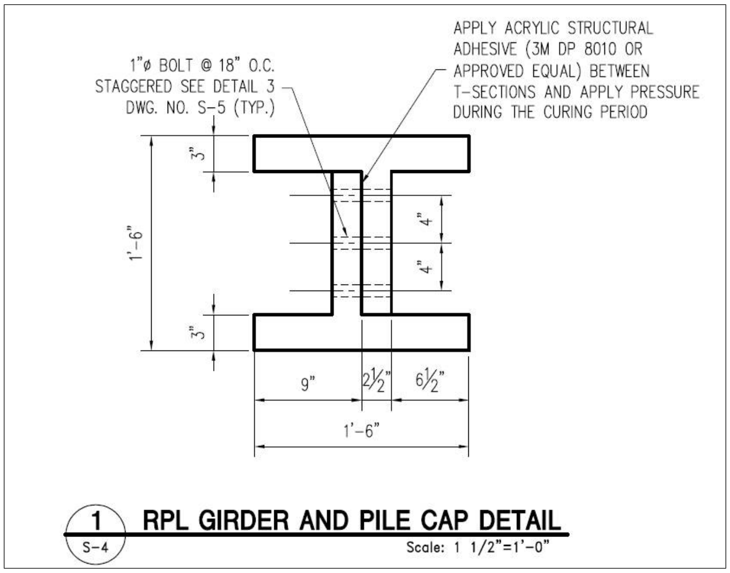


Figure 12. Three thermoplastic bridges constructed at Camp Mackall are:
Bridge T-8518 (top); T-8519 (middle) and T-8520 (bottom).
Foreground of bottom photo shows concrete approach added to Bridge T-8520 to accommodate a higher traffic volume than on Bridges T-8518 and T-8519.

3.1.2 Materials

Thermoplastic composite lumber products are produced by using a unique, immiscible polymer blending, extrusion, and custom molding process that creates a material with the flexibility of HDPE and the stiffness and strength of fiberglass. The immiscible polymer blending process combines post-consumer recycled HDPE and automotive bumper scraps (consisting of fiberglass) in a manner that specifically increases the stiffness and strength, creating a product with properties that exceed those

predicted by the law of mixtures for the individual materials. This mixture is then pushed through a screw-and-barrel extruder.

The specialized extrusion process uses less fiberglass but still produces a product equivalent in strength to that of a material containing three times as much fiberglass. This low fiberglass content is critical since fiberglass is both difficult to dispose of and irritating to the skin. The extruded material is then pushed into a mold to create the product lumber. The molding process allows the product lumber to be produced in a variety of cross-sectional geometries and lengths. Thus, products can be produced with different moments of inertia (I), and the flexural rigidity (modulus of elasticity (E) x I) of the member can be adjusted to achieve the desired mechanical properties and performance (Jackson and Nosker 2009).

The resulting composite has a rough, no-slip, grain-like surface, specific strength greater than steel, and high creep[6] resistance. This high creep resistance results from the material design, which incorporates 600 psi (4.1 MPa) of allowable tensile, compressive, and flexural stress. This value is well below the tested minimum ultimate strength. In other words, if a tank were to be parked on a bridge constructed of this material for 25 years, once driven off the bridge would return to its original shape with inconsequential residual deformation.

The glass fiber-reinforced thermoplastic composite lumber, which incorporates small quantities of foaming agents and other additives – to reduce the occurrence of voids and increase creep resistance – has a modulus of elasticity between 350,000 and 400,000 psi (2,410-2,760 MPa) and a minimum ultimate strength of 3,500 psi (24 MPa). Comparatively, virgin high-density polyethylene has an elastic modulus and ultimate strength of 160,000 psi (1,100 MPa) and 3,500 psi (24 MPa), respectively (Modern Plastics 1996). Pine and oak, the two most common sources for wood lumber, have moduli of elasticity that exceed 1 million psi (6,900 MPa) and strengths of 2,400 psi (17 MPa) and 3,500 psi (24 MPa), respectively, when measured along the growth axis (USDA 2010). Accelerated weather tests have demonstrated that this lumber has an estimated lifespan that exceeds 50 years and requires little maintenance.

[6] Creep is the slow, permanent deformation of a material that occurs over time as a result of prolonged external loads or stresses below the elastic limit. Creep is influenced by load magnitude,

3.2 Construction

The original intent was to build and evaluate a thermoplastic composite bridge as a replacement for a conventional wood timber bridge with an AASHTO load rating of H-20. To accommodate future training requirements, Fort Bragg asked if the new thermoplastic Bridge T-8518 could be designed to cross a 71-ton (64.4 Mg) M-1 Abrams tank. The research team proceeded to design, build, and test a bridge that would provide the required load capacity at a cost that would be competitive to the first cost of a traditional wood timber bridge carrying the same load but with the increased durability requiring minimal maintenance over its 50-plus year life cycle.

Construction of Bridges T-8518, T-8519, and T-8520 was similar to typical timber construction of short-span wood bridges, but not exactly the same. Generic considerations for constructing with thermoplastic composite materials are provided in Appendix B.

From the ground up, the basic construction design consists of rows of pilings, with pins holding I-beam piling caps to each row of pilings. Atop the piling caps is fastened a steel sill plate that was predrilled with holes to align with the girders that run the length of the bridge, touching edge to edge. The girders are through bolted to the pile caps. Decking is affixed to the girders with deck screws, and a railing is affixed to the edges of the bridge.

The structure consisted of 12 in. (30.5 cm) round pilings, with groups of 3 at the abutments and groups of 4 between the two end abutments. The outer piles in each row of 4 were driven at small angles towards the center of the bridge for increased lateral stability. For Bridge T-8518, the pilings only penetrated to a soil depth of 30 ft (9 m) or so when the 37.5 ton (34 Mg) refusal limit was hit. On Bridge T-8519 however, the soil borings indicated that refusal might not come until about twice that depth. Since the pilings were available in 45 ft (13.7 m) lengths, they were spliced with a Schedule 40 steel pipe and driven to about 60–65 ft (18–23 m) for Bridge T-8519. Pilings were driven using a vibratory hammer and a diesel-powered 4,000 lb (1.8 Mg) hammer on Bridge T-8518. Pilings for Bridge T-8519 were first driven with a 1,000 lb (453 kg) bell hammer, followed by the vibratory hammer, and then finally the 4,000 lb (1.8 Mg) diesel-driven hammer. Figure 13–Figure 16 detail the installation of pilings.

Figure 13. Piling being dropped in place by a crane and readied for driving with vibratory hammer.

Figure 14. Vibratory hammer in place and driving pile.

Figure 15. Splicing piles to achieve the depths needed for 37.5 ton (34 Mg) refusal at Bridge T-8519.

Figure 16. The 4 ton hammer in place and driving piling to 37.5-ton (34 Mg) limit.

The sequence for piling installation was as follows: pilings were measured level and cut; pilings were pinned to I-beams acting as the pile caps with 28 in. (71 cm) long, 1 in. (2.54 cm) diameter, smooth stainless steel rods; pilings were driven into an interference fit; and pilings were capped by a stainless washer that was tungsten inert gas (TIG)-welded on (**Error! Not a valid bookmark self-reference.**–Figure 20).

Figure 17. Trimming piling to be level.

Figure 18. Drilling hole through pile cap in preparation for pin insertion.

Figure 19. Hammering pin home through pile cap and into pile.

Figure 20. Pile caps in place and pinned.

Each I-beam was factory-assembled from two T-beams that were held together with 1 in. (2.54 cm) diameter through bolts and glued. The pattern for bolting was staggered between one bolt in the center and then two spaced near the top and bottom of the flange, repeating every 18 in. (46 cm). Details of the fabrication of these large I-beams are given in Appendix A of this report (see Design Drawings, Detail 1, Figure A7; and Detail 3, Figure A8). Close-up photos of the actual products are shown in Figure 21.

Figure 21. Top photo is close-up showing I-beam made from two T-beams; bottom photo shows bolt pattern on the beam web.

There were 3 x 12 in. (7.6 x 30.5 cm) stiffeners affixed to the inside of the pile caps at 18 in. (46 cm) intervals, using screws and glue. The pile caps had 1 in. (2.54 cm) thick steel plates attached that were to be placed between the pile cap and the girders. These plates had holes precision-drilled in them to act as a template for construction. In addition to serving as a template, the sill plate serves to distribute stress over larger sections of the pile cap. Each plate was carefully placed on each pile cap by using laser sighting. Girders were affixed to the pile caps with four 1 in. bolts per joint, and the ends featured 4 in. (10 cm) slots that were 1 in. (2.54 cm) wide, to allow for thermal expansion. See Figure 22–Figure 26.

Figure 22. Installing stiffeners in pile caps, using screws and glue.
Note 1-in. (2.54 cm) steel plate atop each pile cap.

Figure 23. Drilling three holes in a line in preparation to cut thermal expansion slots.

Figure 24. Three holes drilled to connect with a saw and create the thermal expansion slots.

Figure 25. Bridge abutment, showing thermal expansion slots in girders.

Figure 26. Decking and the abutments with the girders installed.

Decking consisted of 3 x 12 in. (7.6 x 30.5 cm) boards that were slightly longer than the 16 ft 6 in. (5 m) width of the bridge. These boards were held in place by 4 M5 zinc-plated steel deck screws per joint initially, with more screws added later (in the form of a modification to Bridge T-8519) to account for the uplift forces when a steam roller crosses the bridge structure and is putting the load on one board at a time (Figure 27).

Railings were affixed to the edge of the bridges and bolted with lag bolts. Later, as part of the same modification mentioned above, rub railings were added in the form of railroad ties bolted to the edge girders with long side installed vertically (Figure 28).

Figure 27. SGT Schrull, Camp Mackall Facility Management, installing deck screws.

Figure 28. Side of deck, showing profile of bridge with railing details.

3.3 Load testing

3.3.1 Initial load testing

Bridge T-8518 was completed in late May 2009 and, during the week of 8 June 2009, load tests were conducted by the Army's Bridge Inspection Team and their contractor, Bridge Diagnostics Inc. The bridge was instrumented with 64 strain transducers, 8 linear variable displacement transducers (LVDTs), and 6 functional rosette strain gages on the beam webs. Initial load tests were conducted using a heavy dump truck (dual axles in the rear) empty and loaded with rock. Details of load testing can be found in ERDC/GSL TR-10-19 (Commander and Diaz-Alvarez 2010a).

3.3.2 Load testing with M-1 tanks

On 11 June 2009, an M-1 tank crossed Bridge T-8518 (Figure 29). With the 36-ton (32.7-Mg) dump truck, the deflection at midspan was 0.216 in. (5.49 mm), including pier deflections. With the M-1 tank, the deflection at the midspan was 0.525 in. (13.3 mm) including pier deflections. On 17 September 2009, Bridge T-8518 was again tested by crossing the M-1 tank

at different speeds. Full results are reported in ERDC/GSL TR-10-19 (Commander and Diaz-Alvarez 2010a).

The elastic modulus, E, used in the design calculations was 350 ksi (2,400 MPa). The load test results indicate that E is closer to 400 ksi (2,760 MPa). Assuming E equals 400 psi (2,760 MPa), the maximum recorded strain and stress with the 36 ton (32.7 Mg) dump truck was 637 microstrain and 255 psi (1.76 MPa). For the M-1 tank, the maximum recorded strain and stress was 740 microstrain and 296 psi (2.04 MPa). As a result of this load test, the bridge was given a load rating of 73 tons (66.2 Mg) for tracked vehicles and 88 tons (79.8 Mg) for wheeled vehicles.

Bridge T-8519 was also load tested with a dump truck and an M-1 tank (Figure 30) with results reported in ERDC/GSL TR-10-48 (Commander and Diaz-Alvarez 2010b).

Figure 29. M-1 tank crossing the thermoplastic composite bridge (T-8518) during initial load testing.

Figure 30. M-1 tank crossing Bridge T-8519.

3.3.3 Long-term, remote performance monitoring

In order to evaluate and verify long-term performance, Bridge T-8518 was instrumented to measure deflections and strains on various components (Lampo et al. 2011; Figure 31 and Figure 32). These instruments included 12 displacement gauges to measure deflections/displacements under load and during changes in temperature to an accuracy of 0.01 inches (0.25 mm), and 10 resistance-type strain gauges adhered directly to the bridge structure to measure strains within the range of +/- 3,000 microstrain. These gauges compensated for temperature and humidity effects, as necessary, to provide accurate strain readings.

Temperature was measured at 16 different locations that corresponded to the installed locations of the displacement and strain gauges. These gauges determined the temperature and the temperature gradients at the locations all over the bridge to an accuracy of 0.1°F (0.06°C).

Figure 33 shows a weather station that was added to record temperature, humidity, rainfall, and wind, as well as ultraviolet (UV) radiation in the 315-400 nm range (UV-A). Of these weather factors, UV-A radiation is the

most destructive to the polyolefin type of polymers that are primarily used in thermoplastic composite lumber and timbers.

Data from the gauges is automatically collected at preset time intervals. Also, whenever a vehicle passes over the bridge, an image is captured of the vehicle and data is collected as a result of the passage (Figure 34). Note that Figure 34 shows that time and date stamps were placed on recorded images so that the data could be correlated to the respective load condition.

The bridge structure also was load tested at six-month intervals with both tracked and wheeled military vehicles of known mass to look for any changes in overall structural performance. Sensors connected to a data recording system were able to store output data for a minimum of 14 days. Each load event collected for the event's duration. Data collected are remotely transmitted to a computer for data analysis or to provide an alert should an overload condition, failed component, or failed sensor or gauge be detected.

In addition, individual boards made from the same material as the bridge structure and exposed to the weather at the bridge site were mounted on an exposure rack for periodic removal and testing in the laboratory. This work measured mechanical property differences compared to unexposed samples over time.

Bending tests were conducted by PFS Corporation of Cottage Grove, Wisconsin, on five of the original fifteen boards that were never exposed to the elements. They also tested five boards removed after 6 months and five boards removed after 12 months of outdoor exposure at the bridge site (see Appendix R in Lampo et al. 2011). All the boards were tested in bending per *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic Lumber and Related Products* (ASTM D6109).

The specimens were loaded at a uniform crosshead speed of 0.71 in. (1.8 cm) per minute, until the specimen was no longer able to sustain increasing load. A typical failure consisted of excessive deflections. None of the specimen boards ruptured. These test results are shown in Table 2.

Table 2. Strength and modulus of elasticity (stiffness) versus time of outdoor exposure (Table 13 in Lampo et al. 2011).

Months of Exposure	Average Bending Strength (psi) / (MPa)	Average Modulus of Elasticity (Secant @ 1% Strain) (psi) / (MPa)
0	4,150 / 28.61	202,705 / 1,398
6	4,284 / 29.54	207,182 / 1,428
12	4,217 / 29.08	203,674 / 1,404

The average strength in bending was 4,200 psi (29 MPa) and the average modulus of elasticity, E, in bending was 205,000 psi (1,400 MPa). Within experimental error, the results of the boards after 6 and 12 month exposures were the same as the unexposed specimens. Specimens removed from the exposure rack at the bridge site at 6 months and 12 months showed no visible signs of degradation, such as fading or discoloration, compared to the baseline, unexposed specimens. No mechanical or physical degradation is indicated as a result of exposure of the materials to the conditions at Camp Mackall.

Figure 31. Strain and temperature gauges are visible near center of this photo.

Figure 32. Laser sensors to measure displacements at midspan.

Figure 33. Weather gauges and a camera are part of the remote performance monitoring setup at right.

Figure 34. A remote image system is activated by a vehicle crossing. Initial settings had to be tuned down as the system was so sensitive at first it was detecting deer crossings.

3.3.4 Later testing

Additional load tests were conducted in August 2010 using an approximate 17-ton (15.4 Mg) wheeled M1089 Wrecker (Figure 35) and a 70-ton (63.5 Mg) tracked M88A2 Heavy Recovery Vehicle (as a substitute for an M-1 tank which was not available during this time). Initially, the vehicles were driven over the bridge at very slow speeds, stopping at the point of maximum deflection. After five minutes, the vehicle was driven off, and bridge recovery was observed. The vehicles were then driven over the bridge at increasing speed increments that reached 25 mph (40 nautical miles/hr) to observe the effects of vehicle speed on the bridge response. The deflections were within the expected values, and there were no indications of creep or material structural degradation when results were compared to previous load tests conducted during September 2009 and January 2010. Details of this later testing are presented in ERDC/CERL TR-11-43 (Lampo et al. 2011).

Figure 35. Wheeled M1089 Wrecker is positioned for load testing of Bridge T-8518.

4 Lessons Learned

Following completion of the construction and testing of the two bridges, several things related to the design and construction of the bridges became obvious to look at as possible improvements to be taken in consideration of future bridges –Bridge T-8520 being one such case, as the third bridge at Camp Mackall to be built from the new thermoplastic material.

4.1 Modifications to deck board–girder connections

The key lesson we learned about designing and constructing these two bridges came during the testing phase, before actually driving a tank over the bridges. The bridges were designed for a number of wheeled, loaded vehicles and the Abrams M1, all of which distribute loads over the bridge along its length. One of the testing vehicles used was a 30-ton steam roller. The steel roller applies 300 lb (136 Kg) of force per linear inch (2.54 cm) along the contact between the roller and the surface. This contact area is almost as thin as a line and lies only on one deck board at a time. The prospect of a steam roller going over the bridge was not listed in the design considerations, and that omission was immediately apparent when this testing was performed. Pictures of the actual steam roller first driving over Bridge T-8519 do not exist, but accounts of what happened do. The steam roller caused many of the planks on Bridge T-8519 to partially dislodge the screws located on the outside few girder–deck board connections as it passed over the bridge (Figure 36–Figure 38).

Significant damage to the deck surface's connections to the girders will lower the load sharing between the girders and result in higher stresses occurring directly under wheeled loads. The bridges were designed to utilize the deck–girder connections to help lower the maximum stresses achieved during loading.

Figure 36. Deck boards showing the sides of Bridge T-8519 loosened and dislodged after the bridge was traversed by a 30-ton (27.2 Mg) steam roller.

Figure 37. The edge of some deck boards on Bridge T-8519, showing that one board one is ½ in. (1.25 cm) higher than the other.

Figure 38. The edge of some other deck boards on Bridge T-8519, showing that one is ½ in. (1.25 cm) higher than the other.

After this damage occurred on Bridge T-8519, Dr. Nosker (associate professor at Rutgers University) and Steven Sweeney (ERDC-CERL structural engineer) discussed modifications to the bridges. It was decided to modify Bridge T-8518 before the tank crossing on 11 June. The modifications made to Bridge T-8518 were to insert an additional three screws in the middle of each deck board–girder connection in the outermost four girders (from edges of bridge) along the girder centers.

The modifications on Bridge T-8519 consisted of removing all of the four edge screws that were in place for each of the outermost girder–decking joints and replacing them with longer screws because the dislodged screws were lacking holding resistance. Then, five more screws were placed in the outermost four of the girder-decking interfaces, as per the modification contract's specifications. Already in place were three screws along the girder's central axis and one screw at the girder edges on each side between the other screws. The modification resulted in a total of nine screws for each girder-deck board connection for each of the outermost four deck boards on each side of the bridge.

In addition, the bottom stiffening boards were inspected and found to have no damage whatsoever. Following this modification work, the steam roller that originally caused the damage to this bridge was again used to cross the bridge; there were no subsequent incidents and no noticeable deflection (Figure 39–Figure 41).

Bridge T-8520 used 6 in. long (15 cm) #14 deck screws, similar to the modification to the deck boards on bridge T-8519. When last inspected during May 2015, the decking showed no signs of lifting or breakage of fasteners.

Figure 39. An edge view of Bridge T-8519 after repair of the decking.

Figure 40. A top view of Bridge T-8519 after repair of the decking.

Figure 41. A steamroller crosses Bridge T-8519 after repair of the decking. No noticeable deflections or other types of failures were observed during the crossing.

4.2 Installation of curbing

A second lesson learned is connected to the first—that is, the bridges as originally designed did not include curbing. This lesson has two implications. The first implication is that any vehicle that is too far off to one side will contact the rails and posts first, almost certainly causing damage to the bridge. The second implication is that the curbing could be thru-bolted through the decking and outer girders, thus holding the deck boards down with a tremendous force. The first modification to Bridge T-8518 specifically addressed this issue and subsequently, curbing was installed as shown in Figure 42–Figure 44.

4.3 Key design findings

- The next-generation bridge design should consider use of tongue-and-groove decking to enable load sharing with the proper number and length of deck screws.

- The central pilings are grouped on close spacing to reduce the bending stress developed in the piling caps. The pile caps are also cantilevered at the ends. The recommendation is to increase the spacing of the center piles to enable load sharing across the pile cap.

- The sheet piling on Bridges T-8518 and T-8519 did not require a drop-off of more than a few feet, and the use of fiberglass sheet piling was excessive. It is recommended that the next bridge use a thermoplastic sheet piling of an appropriate configuration for the site. Vinyl sheet piling was used with Bridge T-8520.

- One thing to note is that the most time-consuming step of putting the substructure in place proved to be drilling holes in the girders and the cutting the slots for thermal expansion (Figure 45). The slots could be cut easier and faster in a shop environment. In addition, sets of girders and blocking could be factory-assembled as panels to enable faster construction in the field. This factory assembly process was used for the railway bridges at Fort Eustis and the bridge over the River Tweed in Scotland.

- The largest of the four hammers used to drive pilings on Bridge T-8519 (a 4,000 lb [1.8 Mg] hammer) was probably larger than needed.

- The original design for the two bridges specified the number of 5 in. long deck screws to be 6 in. on center, which resulted in approximately 2.67 screws per square foot (0.248 per square meter). The experience with the steam roller on Bridge T-8519 illustrated that the original specification for deck screws called for too few and too short screw size. Therefore, 5.5-in. (14 cm) long, #14 deck screws at three rows per plank were used for Bridge T-8520, and no lifting problem has been observed. Rub rails (made of railroad ties) should be through-bolted into place through the girder and decking in order to act as both curbing and an additional retention feature for the deck boards.

- On Bridges T-8518 and T-8519, a problem was observed where some of the screws holding the railing boards at the ends have pulled out from the post (Figure 46). This issue resulted in a change in construction wherein the railing boards are fixed at one railing post connection and a slotted hole (5/32 in. [0.4 cm] by ½ in. [1.25 cm]) provided at the other railing post connection. This design change was made to allow for expansion and contraction without placing undue stress on the fasteners that would cause them to pull out of the post. Subsequently, 4 in. (10.2 cm) long screws were specified for each of the subject bridges. Of course, the use of slightly larger (i.e., #16) and longer screws would also help with this potential pull-out issue.

Figure 42. The bottom railing on Bridge T-8518 was removed and fastened to the deck surface, with spaces approximately every 6 ft (1.8 m) to allow water to run off.

Figure 43. Holes were drilled through the decking and girder substructure to allow for a thru-bolt connection.

Figure 44. Bridge T-8518 with the rub rails installed.

Figure 45. Slotted connections to accommodate thermal expansion/contraction.

Figure 46. Observed problem of screws holding the railing boards that pulled out from the post at the ends of the boards as a result of forces exerted by expansion-contraction of the railing boards.

5 Economic Analysis of Bridge Materials

5.1 Background assumptions

The goal of this ITTP project was to demonstrate and validate a low-maintenance, affordable structure that uses recycled materials and avoids wood components that require chemical treatments to fight rot and insect attack as well as costly routine maintenance to repair or replace deteriorated members. That has been done—the type of thermoplastic timber used in the project was proven to be a structural-grade, reinforced plastic lumber suitable for load-bearing construction.

One potential result of environmental degradation of wood bridges is a reduced load capacity that can interfere with or jeopardize critical training activities. Key advantages of thermoplastic lumber over wood are that it is not subject to degradation and it does not leach harmful chemicals into the soil or groundwater (as it does not require any application of protective coatings or preservatives that can emit environmentally damaging volatile organic compounds into the atmosphere).

In order to divert large quantities of recycled materials from landfills, these thermoplastic materials need to be used in civil construction projects instead of the smaller quantities used making plastic picnic tables and benches. For example, construction of the thermoplastic version of Fort Bragg's Bridge T-8518 diverted 85,000 lb (38.5 Mg) of recycled plastics from landfills. The bridge now consists of 94% recycled materials, including glass, vehicle bumpers, and approximately 85,000 lb (38.5 Mg) of high-density polyethylene plastic (same plastic as milk jugs). The pilings, girders, substructure, decking, and railings were all thermoplastic with steel being used only in the bolts and sill plates.

5.2 Comparison of alternative bridge structures

5.2.1 Alternative 1

Engineering personnel at Axion International, New Providence, New Jersey, first provided ERDC-CERL with a general 2009 cost estimate for the type of wood bridge similar to the 540 sq ft (50 m^2), HS-20 rated, wood bridge at Wharton State Forest before its 2003 replacement. To compare those costs with the Fort Bragg thermoplastic I-beam bridges, the following adjustments were made to the original estimated first cost:

1. Multiply original first costs by the estimated increase to construct an HS-25 rated bridge relative to an HS-20 bridge.
2. Multiply original first costs by the location factor for Fayetteville, NC (per RS Means 2009). A ratio was unnecessary as the original estimated first cost was generalized and based on normal conditions. Therefore, a location factor representing a city near Wharton State Forest was not needed.

Axion also obtained the estimated amounts for repair and maintenance (R&M) and the years in which these R&M costs would take place from a former wood bridge building contractor based on a 2,600 sq ft (242 m^2), HS-20 rated bridge. The costs were generalized and based on normal conditions. These costs were then adjusted as follows:

1. Multiply by the ratio 540 sq ft/2600 sq ft (50 m^2/242 m^2) to get the pro-rata costs for the smaller dimensions of the Wharton State Forest Bridge.
2. Multiply by the increase in costs for an HS-25 rated bridge as compared to an HS-20 bridge.
3. Multiply by the 2009 Fayetteville, North Carolina, location factor. (However, this factor was unnecessary as the original R&M costs were generalized and based on normal conditions. Therefore, a location factor representing a city near Wharton State Forest was not needed.)

The wood bridge replacement cost, estimated to occur at the beginning of year 21, was the same as the bridge's first cost at the beginning of year 1. In addition, demolition and disposal costs for the original bridge were estimated at $37.50 per sq ft ($403.65/m^2). Total demolition and disposal costs were calculated by using the $37.50 per sq ft ($403.65/m^2) multiplied by the square footage of the bridge (540 sq ft [50 m^2]) and then multiplied by the 2009 location factor (.805) for Fayetteville, NC.

5.2.2 Alternative 2

Alternative Case #2 was based on a 2009 Fort Drum "hybrid" bridge made of laminated wood deck, steel, and concrete that is HS-25 rated and 693 sq ft (64 m^2) in size. Adjustments made to obtain the first cost of this bridge involved the following:

1. The total contract award's cost of $841,355 included removing the existing bridge, constructing a temporary bridge, upgrading the trail,

supplying engineering drawings, conducting a geotechnical survey, and providing document submittals. Costs of those items, not involving new construction ($225,119), were subtracted from the total award cost to arrive at the estimated first cost for construction and materials ($616,236).

2. The amount obtained in Step 1 was multiplied by the ratios of .805 and .964, representing the RS Means 2009 location factors for Fayetteville, NC, and Syracuse, NY, respectively (the closest available location factors to Fort Bragg and Fort Drum).

The types of R&M anticipated for the hybrid bridge were similar to the wood bridge. However, painting the steel girders was an additional maintenance cost for the hybrid bridge alternative. In addition, according to Axion, the laminated wear deck of the hybrid bridge will last twice as long as a typical wood deck, but will incur 50% higher replacement costs.

The replacement costs of the hybrid bridge at the beginning of year 31 were based on the demolition and disposal costs of the old bridge and first costs associated with a replacement bridge.

It should be noted that that there is a limitation of length relative to extrapolating cost per area for the hybrid bridge. Given nominal 12–14 ft (3.6–4.2 m) span lengths for typical wood or thermoplastic bridges and excluding an economy of scale discount for the very long bridges, the cost per square area of these bridges will be relatively linear as the number of spans is increased. For the hybrid bridge used in this life-cycle cost analysis, the cost of a steel reinforced concrete pier would need to be added and the overall first cost and life-cycle costs would increase. However, for short span 30-60 ft (9–18 m) long bridges, the costs in this current analysis are considered valid.

5.2.3 Alternative 3

Alternative 3 was based on the 2009 Fort Bragg T-8518 thermoplastic, HS-25 rated (73 ton [66 Mg] load rating for tracked vehicles and 88 ton [80 Mg] for wheeled vehicles), 639 sq ft (59 m^2) bridge. First costs were obtained by reviewing the contract file and adding the relevant modification costs. Per Axion's personnel, R&M costs are expected to be minimal with fastener replacement costs of $4,000 every 10-15 yr. Taking a conservative stance, those costs are assumed to occur every 10 years.

5.2.4 Alternative 4

Alternative 4 was based on the 2009 Fort Bragg T-8519 thermoplastic, HS-25 rated, 756 sq ft (70 m^2) bridge. As with Alternative 3, first costs were obtained by reviewing the contract file and adding the relevant modification costs. Part of the increase in first costs was due to T-8519's greater length (relative to bridge T-8518), and the piling depth needed for T-8519 was twice the depth needed for T-8518 based on soil boring information.

The fastener replacement costs of $4,000 were multiplied by the ratio 639 sq ft/756 sq ft (~ 59 m^2/70 m^2) to compute the estimated costs for this larger bridge. As with Alternative 3, these costs were assumed to occur every 10 years.

5.3 Results analyzed with net present value discount factors

5.3.1 Case 1 – NPV discount factor 3%

Using a net present value (NPV) factor of 3%, the estimated first cost of the wood bridge is $600/sq ft ($6,458/m^2), the hybrid bridge is $743/sq ft ($7,998/m^2), the thermoplastic bridge T-8518 is $625/sq ft ($6,727/m^2), and the thermoplastic bridge T-8519 is $700/sq ft ($7,535/m^2). However, due to the longer life and lower R&M costs associated with the thermoplastic bridges, the NPV life-cycle costs are as follows:

- Wood bridge: $981/sq ft ($10,559/m^2)
- Hybrid bridge: $1,101/sq ft ($119,490/m^2)
- Thermoplastic bridge T-8518: $636/sq ft ($6,846/m^2)
- Thermoplastic bridge T-8519: $711/sq ft ($7,653/m^2)

Comparing these NPV life-cycle costs, the NPV savings (costs) relative to the wood bridge are as follows:

- Wood bridge: n/a
- Hybrid bridge: $119/sq ft ($1,281/m^2) in additional costs
- Thermoplastic bridge T-8518: $346/sq ft ($3724/m^2) in cost savings
- Thermoplastic bridge T-8519: $270/sq ft ($2,906/m^2) in cost savings

5.3.2 Case 2 — NPV discount factor 5%

Using an NPV factor of 5%, the estimated first cost of each of the bridges is the same as in Case 1. Using a higher discount factor, the NPV life-cycle costs are lower relative to Case 1. The NPV life-cycle costs for Case 2 are as follows:

- Wood bridge: \$863/sq ft (\$9,289/m^2)
- Hybrid bridge: \$952/sq ft ((\$10,247/m^2)
- Thermoplastic bridge T-8518: \$632/sq ft (\$6,803/m^2)
- Thermoplastic bridge T-8519: \$708/sq ft (\$7621/m^2)

Comparing these NPV life-cycle costs, the NPV cost savings relative to the wood bridge are as follows:

- Wood bridge: N/A
- Hybrid bridge: \$89/sq ft (\$958/m^2) in additional costs
- Thermoplastic bridge T-8518: \$230/sq ft (\$2,476/m^2) in cost savings
- Thermoplastic bridge T-8519: \$155/sq ft (\$1,668/m^2) in cost savings

As expected, the NPV cost savings of the thermoplastic bridges are lower in Case 2 compared to Case 1. This difference is due to the higher discount factor in Case 2 and the fact that the thermoplastic bridges have minimal R&M costs relative to the other types of bridges.

5.4 Benefits not quantified in economic analysis

There are numerous potential benefits of a thermoplastic bridge that were excluded from the economic analyses. In an effort to be as conservative as possible, authors deemed the subjective nature of estimating the dollar amounts associated with these benefits was beyond the scope of this project. These additional, nonquantified, environmental and economic benefits are noted below and summarized in Table 3, and they can only strengthen the argument for using thermoplastic bridges.

5.4.1 Nonquantified environmental benefits

- Product uses large quantities of materials otherwise considered waste (diverts waste plastics from landfills).
- Product is recyclable at end of life cycle.

- As a substitute for wood from trees, plastic lumber can help reduce greenhouse gases (Lampo and Nosker 2001).
- Thermoplastic lumber is inherently resistant to rot and insects without poisonous chemical treatments.
- Thermoplastic lumber and related products can be effectively used in wet/damp environments with no added chemicals because they are inherently resistant to degrading effects of moisture and weather.

5.4.2 Nonquantified economic benefits

- I-beam design equates to less material used to carry the same load compared to a wood bridge.
- Product able to withstand very hot and very cold temperatures without biodegradation or oxidation.
- Virtually no maintenance requirements.
- Enhances training capabilities due to shorter construction cycle time and less R&M that would limit access to training lands. In addition, as wood bridges degrade with environmental exposure, their load capacity can diminish and potentially curtail training capabilities.
- Product rated for approximately twice the lifespan of wood bridges.

Additionally, the benefits of thermoplastic bridges can be regarded in terms of the Army's "Triple Bottom Line Plus" as follows:

1. **Performance** (helps the mission)—able to carry more load and can be built as fast or faster than bridges using other materials, resulting in less "down time" (e.g., concrete typically needs 28 days to cure; in addition, concrete is often reinforced with rebar, which is prone to corrosion due to water infiltration and can result in cracking of the concrete). The design process and the construction skills and tools used for thermoplastic bridges are similar to those for traditional wood bridges.
2. **Environmental**—keeps plastics out of landfill, uses no chemical-treatment, requires no permits, and generates no hazardous waste to dispose of when it needs to be replaced.
3. **Economic**—life-cycle costs are lower than wood or hybrid bridges.

Table 3. Comparison of material attributes and bridge life-cycle costs.

Bridge Characteristics	Bridge Type / Design		
	Thermoplastic Composite I-Beam	Treated Wood Timber	Hybrid (steel and concrete with laminated wood deck)
Inherent resistance to moisture, corrosion, and insects	Yes	No	No
Chemical treatment	No	Yes	Yes
High recycled content	Yes	No	Partially[1]
Does not biodegrade	Yes	No	Partially[2]
Retain mechanical properties in humid/wet environments	Yes	No	No
Retain mechanical properties over time	Yes	No	No
Resistant to UV light	Yes	No	Partially[3]
Contributes to reduction in greenhouse gases	Yes	No	No
Inherent ductility and toughness (over wide temp.)	Yes	No	Partially[4]
Initial cost (per square foot)	$625	$600	$743
NPV[5] lifecycle costs (per square foot)	$675	$981	$1,101
Expected life (years)	50+	15–20	30+
Relative lifetime maintenance	$	$$$$$	$$$$$

1 – Steel may contain some recycled content.
2 – Steel and concrete do not biodegrade but the wood will.
3 – Steel and concrete resist UV light but not so for wood.
4 – Steel has inherent ductility.
5 – Net Present Value with a 3% discount rate.

5.5 Economic analysis conclusions

Based on the economic analysis, the first cost of the wood bridge ($600/sq ft [$6,458/m^2]) is lower than the hybrid bridge ($743/sq ft [$7,998/m^2]) or the two thermoplastic bridges ($625/sq ft [$6,727/m^2] for T-8518 and

$700/sq ft [$7535/m^2] for T-8519). However, one of the advantages of thermoplastic bridges is their relatively minimal R&M costs. In addition, their estimated 50-year lifespan is substantially longer than the lifespan for a wood bridge (15–20 years) or a hybrid bridge (25–30 years). These advantages lead to life-cycle costs of thermoplastic bridges ($636/sq ft [$6,846/m^2] for T-8518 and $711/sq ft [$7,653/m^2] for T-8519) that are significantly lower than a wood ($981/sq ft [$7653/m^2]) or a hybrid ($1,101/sq ft [$11,851/m^2]) bridge, based on an NPV factor of 3%. Given similarity of design and materials use, similar cost benefits would also be expected for Bridge T-8520.

With respect to widespread application, the innovative thermoplastic composite I-beam bridges have demonstrated that this design and materials should be considered an extremely attractive alternative to replace thousands of wood timber bridges at Army installations and federal and state parks and forests throughout the United States. The use of thermoplastic in construction offers high-volume application that could increase the market for these types of products and result in “closing the loop” regarding a use for recycled plastics. In turn, this use has the potential to lead more manufacturers into the marketplace, resulting in increased competition and further reduction of material costs.

6 Summary and Recommendations

6.1 Summary

Recycled plastic lumber materials have evolved significantly over the years—from the beginning uses in park benches and picnic tables to bridges capable of handling heavy vehicle loading. It is also significant that the most current materials and designs enable such structures to be cost-competitive to traditional treated wood timber designs on a first-cost basis. With its low maintenance requirements over the longer expected life of the structure, thermoplastic composite materials and designs are a clear winner in a life-cycle comparison.

Thermoplastic composite lumber materials are resistant to moisture, rot, insects, and degradation that occurs with natural wood (chemically treated or not), when it is exposed to the outdoor environment. Because the composite lumber does not need toxic chemical treatments to increase its lifespan, it is a better environmental choice than treated wood. While there certainly are property differences between thermoplastic composite materials and natural wood, appropriate design considerations and material formulations (i.e., unreinforced versus reinforced) have enabled these materials to be used in high load-bearing applications for all-types of structures, such as the subject bridges at Fort Bragg.

Both the initial load testing and long-term monitoring, along with the life-cycle economic analysis of Bridge T-8518 and T-8519, validate the beneficial use of these materials and designs for timber bridge applications. The demonstration also proved this innovative bridge design and material is capable of carrying a 71-ton (64 Mg) load.

6.2 Recommendations

6.2.1 Applicability

The innovative thermoplastic composite I-beam bridge demonstration at Fort Bragg shows that this design and materials choice should be considered for replacement of the thousands of wood timber bridges that exist on Army installations and within federal- and state-owned parks and forests throughout the United States. Such application would save considerable time and money since the technology was proven cost-

competitive to wood on a first-cost basis and with lower demonstrated life-cycle costs.

6.2.2 Implementation

A major barrier to more common implementation of thermoplastic composite timbers for bridges is the lack of applicable design guidance. As described herein, several thermoplastic composite bridges have been successfully built and are in daily use. Once the new, previously mentioned, UFC on Composites for Bridge Applications is available, designers should at least be able to specify thermoplastic composites as an alternative to traditional materials and then, let the competitive process decide which material type is finally used (as with the railroad bridges at Fort Eustis). To further aid in the refinement of designs using thermoplastic composite materials, refer to the results presented in ERDC/CERL TR-17-18, Full-Scale Testing of Thermoplastic Composite I-Beams for Bridges (Al-Chaar et al. 2017).

References

Al-Chaar, Ghassan K., Steven C. Sweeney, Richard G. Lampo, and Marion L. Banko. 2017. *Full-Scale Testing of Thermoplastic Composite I-Beams for Bridges*. ERDC/CERL TR-17-18. Champaign, IL: Engineer Research and Development Center-Construction Engineering Research Laboratory (ERDC-CERL).

ASTM D6108. Standard Test Method for Compressive Properties of Plastic Lumber and Shapes. West Conshohocken, PA: ASTM International.

ASTM D6109. Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastic Lumber. West Conshohocken, PA: ASTM International.

ASTM D6111. Standard Test Method for Bulk Density and Specific Gravity of Plastic Lumber and Shapes by Displacement. West Conshohocken, PA: ASTM International.

ASTM D6112. Standard Test method for Compressive and Flexural Creep and Creep-Rupture of Plastic Lumber and Shapes. West Conshohocken, PA: ASTM International.

ASTM D6117. Standard Test Method for Mechanical Fasteners in Plastic Lumber and Shapes. West Conshohocken, PA: ASTM International.

ASTM D6341. Standard Test Method for Determination of the Linear Coefficient of Thermal Expansion of Plastic Lumber and Plastic Lumber Shapes Between -30 and 140 °F (-34.4 and 60 °C). West Conshohocken, PA: ASTM International.

ASTM D6435. Standard Test Method for Shear Properties of Plastic Lumber and Plastic Lumber Shapes. West Conshohocken, PA: ASTM International.

ASTM D6662. Standard Specification for Polyolefin-Based Plastic Lumber Decking. West Conshohocken, PA: ASTM International.

ASTM D7568. Standard Specification for Polyethylene-Based Structural-Grade Plastic Lumber for Outdoor Applications. West Conshohocken, PA: ASTM International.

Axion International. 2011. "Axion International Receives Purchase Order to Supply Materials for First Plastic Bridge Used in Public Highway Applications in U.S." Press release, 21 October. New Providence, NJ: Axion International, Inc.

Commander, Brett, and Henry Diaz-Alvarez. 2010a. *Field Testing and Load Rating of the World's First Thermoplastic Bridge: Bridge T-8518, Camp Mackall, Fort Bragg, North Carolina*. ERDC/GSL TR-10-19. Vicksburg, MS: Geotechnical and Structures Laboratory, U.S. Army Engineer Research and Development Center. Available online at http://acwc.sdp.sirsi.net/client/search/asset/1003401.

_________. 2010b. Field Testing and Load Rating of a Short-Span Thermoplastic Bridge System, Bridge T-8519. ERDC/GSL TR-10-48. Vicksburg, MS: Geotechnical and Structures Laboratory, U.S. Army Engineer Research and Development Center. https://erdc-library.erdc.dren.mil/xmlui/discover?query=1003407.

Finney, Dana L. 2009. "Recycled Plastic Bridge at Fort Bragg Stands Up to M-1 Traffic." *Public Works Digest* 21 (4): 7–8.

Gregorski, Tim. 1998. "Bridge Advances Plastic Lumber Use." *Roads and Bridges* 36(10): 58.

Jackson, L.M. and T.J. Nosker. 2009. "Technology, Applicability, and Future of Thermoplastic Timbers." In *Proceedings of the DoD Corrosion Conference 2009*, held August 10–14 at Gaylord National Resort and Convention Center in National Harbor, MD.

Kim, John S., Vijay Chandra, and Thomas J. Nosker. 2011. "World's First Thermoplastic Railroad Bridges." In *Proceedings of AREMA Annual Conference 2011,* held September 18-21 in Minneapolis, MN.

Lampo, Richard G., and Thomas J. Nosker. 1997. *Development and Testing of Plastic Lumber Materials for Construction Applications*. USACERL Technical Report 97/95, 35–39. Champaign, IL: U.S. Army Construction Engineering Research Laboratory.

_________. 2001. "Environmental Benefits of Using Recycled-Plastic Railroad Crossties Including Reducing Greenhouse Gases." Presentation at Railroad Environmental Conference, Railtec, University of Illinois at Urbana-Champaign, September 25. http://www.railtec.illinois.edu/RREC/overview.php.

_________. 2012. "Degradation-Resistant Material Systems for Timber Bridge Designs." In *Proceedings of SAMPE Tech 2012*, held October 22–25 in Charleston, SC.

Lampo, Richard G., Barry K. Myers, Karl Palutke, and Darryl M. Butler. 2011. *Remote Performance Monitoring of a Thermoplastic Composite Bridge at Camp Mackall, NC: Final Report on Project F08-AR13, Task A-Thermoplastic Composite Bridges*. ERDC/CERL TR-11-43. Champaign, IL: Construction Engineering Research Laboratory–Engineer Research and Development Center.

Lampo, Richard G., James Wilcoski, Vincent F. Hock, Sarah B. Nemeth, Henry Diaz-Alvarez, and Thomas J. Nosker. "U.S. Army Builds Degradation Resistant Bridges." *AMMTIAC Quarterly* 5(4): 3–6.

Modern Plastics Encyclopedia. 1996. Vol. 72: 12, p B-185–6. Edited by Modern Plastics Magazine. New York: McGraw Hill, Inc.

Nosker, Thomas J., Richard G. Lampo, Malcom McLaren, Richard W. Renfree, and Robert Kerns. 1996. "Innovative Structural Design Concepts for Plastic Lumber Materials." In *Proceedings of the Society of Plastics Engineers*, W14–Applications, 3151–3155, ANTEC Conference held in Indianapolis, IN, 5–10 May 1996.

USDA (United States Department of Agriculture). 2010. *Wood Handbook: Wood As An Engineering Material.* General Technical Report FPL-GTR-190, Chapter 4 "Moisture Relations and Physical Properties of Wood," Table 4-2. Washington, D.C.: Forest Products Library, Forest Service, USDA.

Vertech Composites. 2011. "Recycled Plastic Bridge, Summary." Available to download at www.solaripedia.com/13/383/5373/recycled_plastic_bridge_scotland.html.

Appendix A: Bridge Design Drawings and Specifications

This appendix contains a set of engineering drawings completed in 2009 by McLaren Engineering Consultants for the replacement of Bridge T-8518 at Camp Mackall, Fort Bragg, North Carolina. Material specifications are detailed on sheet G-1. Details of the I-beam girders, pile caps, and blocking are shown on sheet S-4.

Also included are selected sheets from the engineering drawings completed by McLaren Engineering Consultants for the replacement Bridges T-8519 and T-8520. Sheets S-2 for both Bridges T-8519 and T-8520 show the staggered layout of the I-beam girders. The staggered layout is required since a single girder is not long enough to span the entire bridge length as for Bridge T-8518. Sheet S-1 for Bridge T-8520 allows vinyl sheet piling as a lower-cost alternative to fiberglass sheet piling which was not the case for Bridges T-8518 and T-8519. Another major change is shown on sheet S-6 for Bridge T-8520 that required #14 flat head screws, 5-1/2 inches long at three rows per plank. Bridges T-8518 and T-8519 had a requirement of 5 inch long screws at 6 inches on center (see sheet S-2 for T-8518). Also shown on sheet S-6 for Bridge T-8520 is the requirement to provide slotted holes for the railing boards.

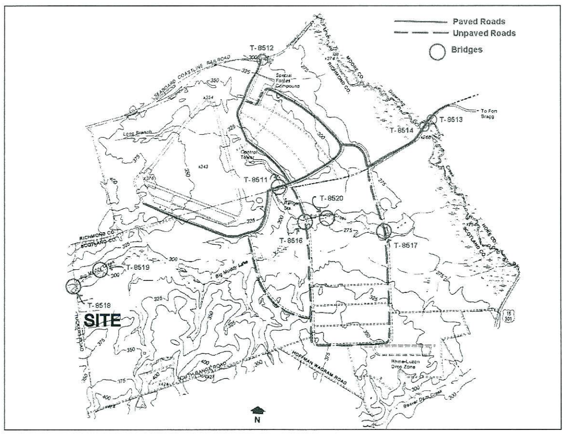
Figure A1. Sheet T-1, site drawing for Bridge T-8518.

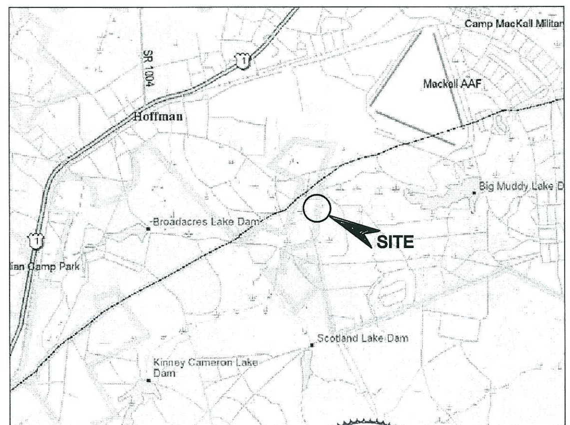
REPLACEMENT OF BRIDGE T-8518

Tuckers Road over Big Muddy Creek

FORT BRAGG, NORTH CAROLINA

FEBRUARY 27, 2009





PREPARED BY

McLaren ENGINEERING GROUP

E-mail: mgmclaren@mgmclaren.com
100 Snake Hill Road, West Nyack, NY 10994
Tel. (845) 353-6400 Fax. (845) 353-6509

NORTH CAROLINA PROFESSIONAL SEAL 17978 ENGINEER MALCOLM G. McLAREN

DRAWING NO. T-1

SHEET 1 OF 10

Figure A2. Sheet G-1, general notes for Bridge T-8518.

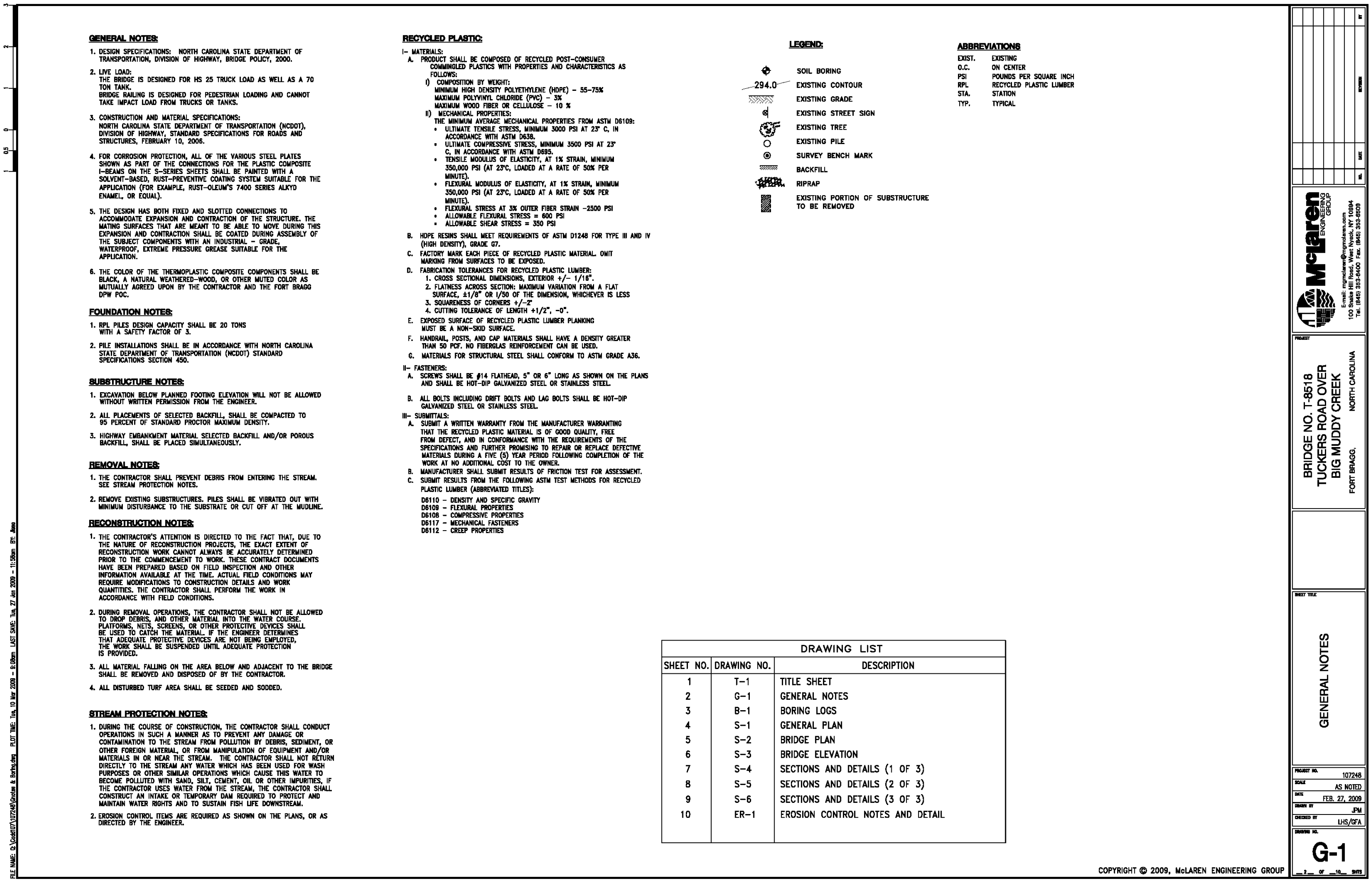


Figure A3. Sheet B-1, boring log for Bridge T-8518.

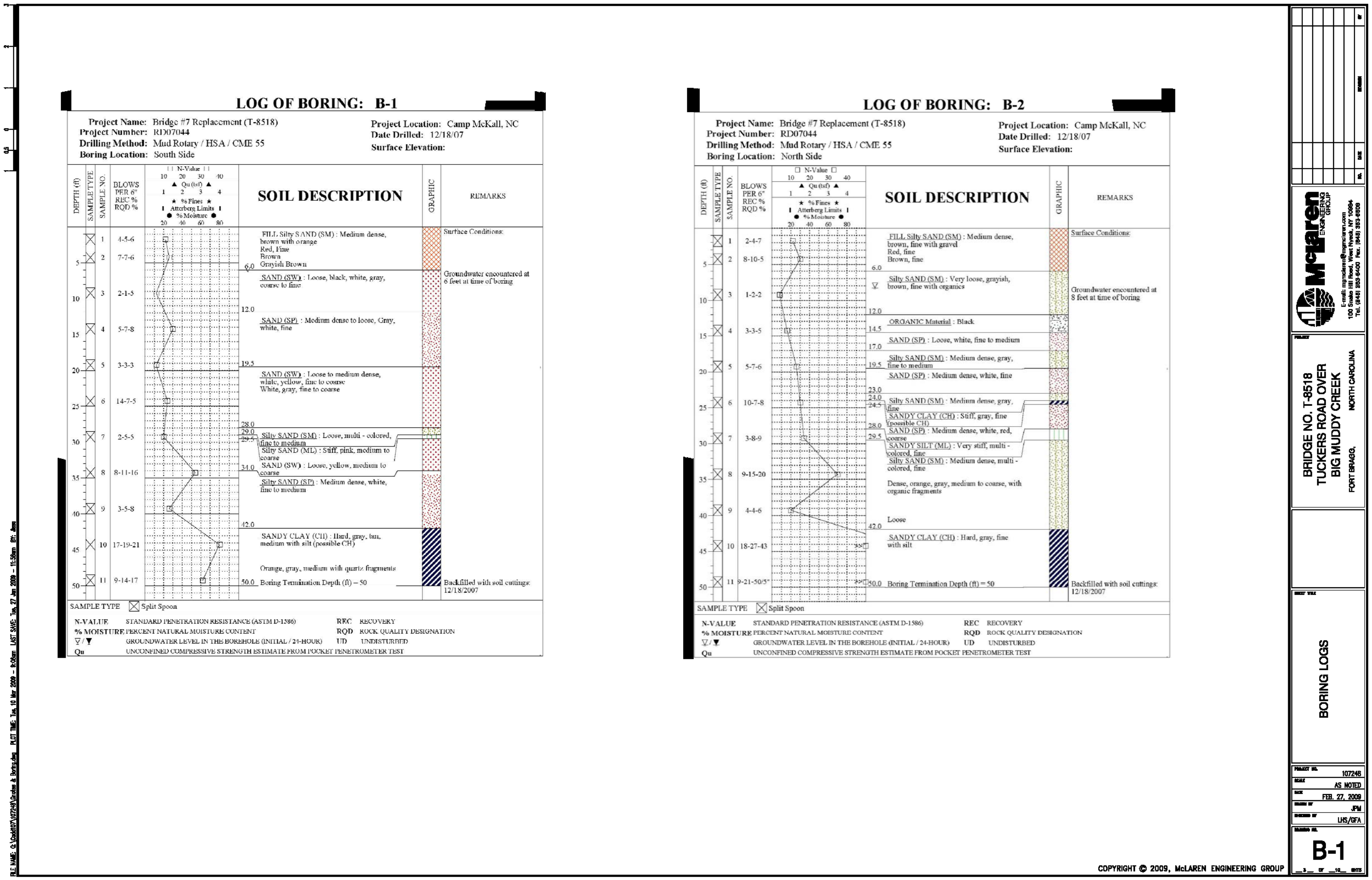


Figure A4. Sheet S-1, general plans for Bridge T-8518.

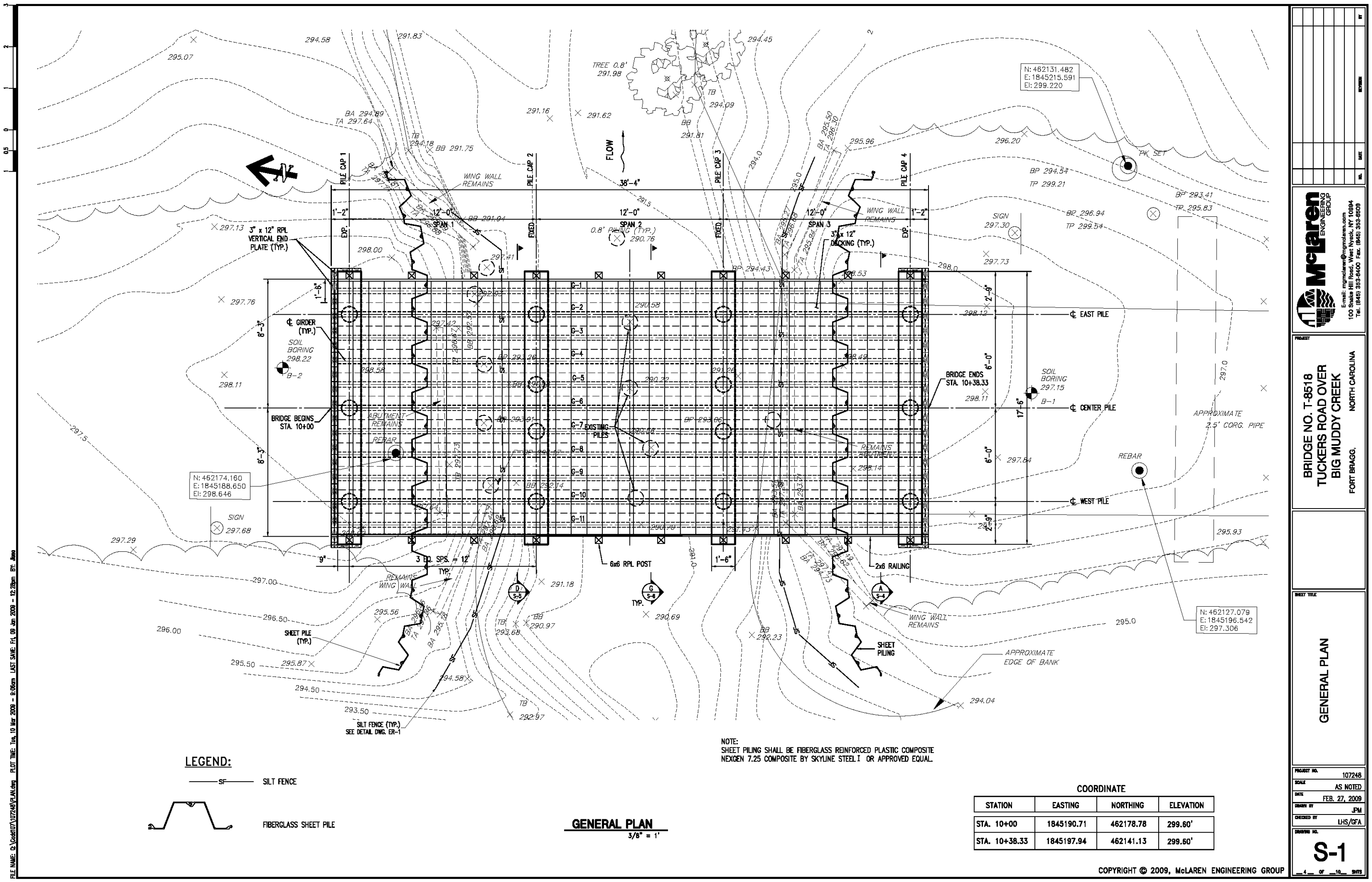


Figure A5. Sheet S-2 of bridge plan for Bridge 8518.

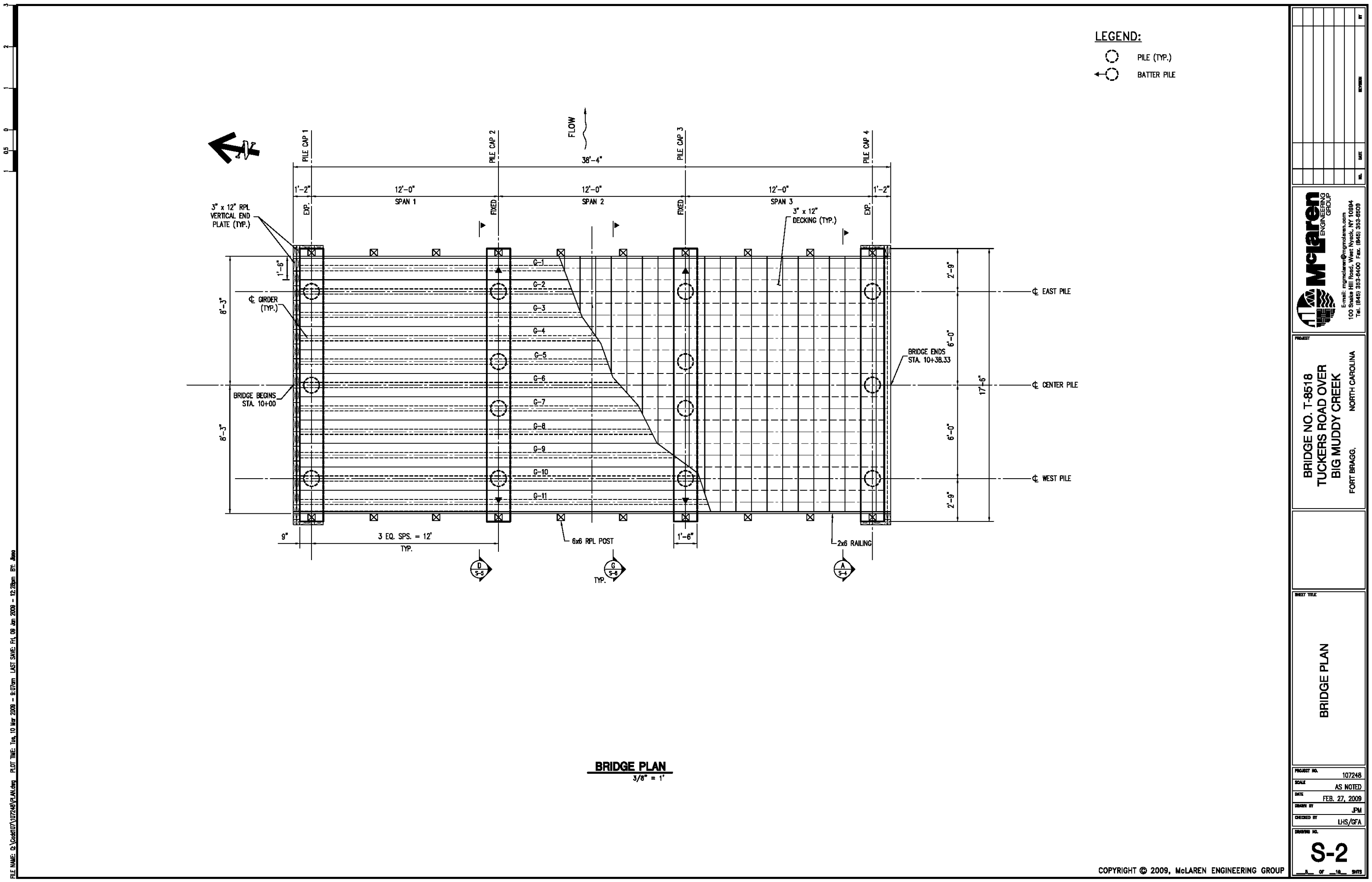


Figure A6. Sheet S-3, bridge elevation for Bridge T-8518.

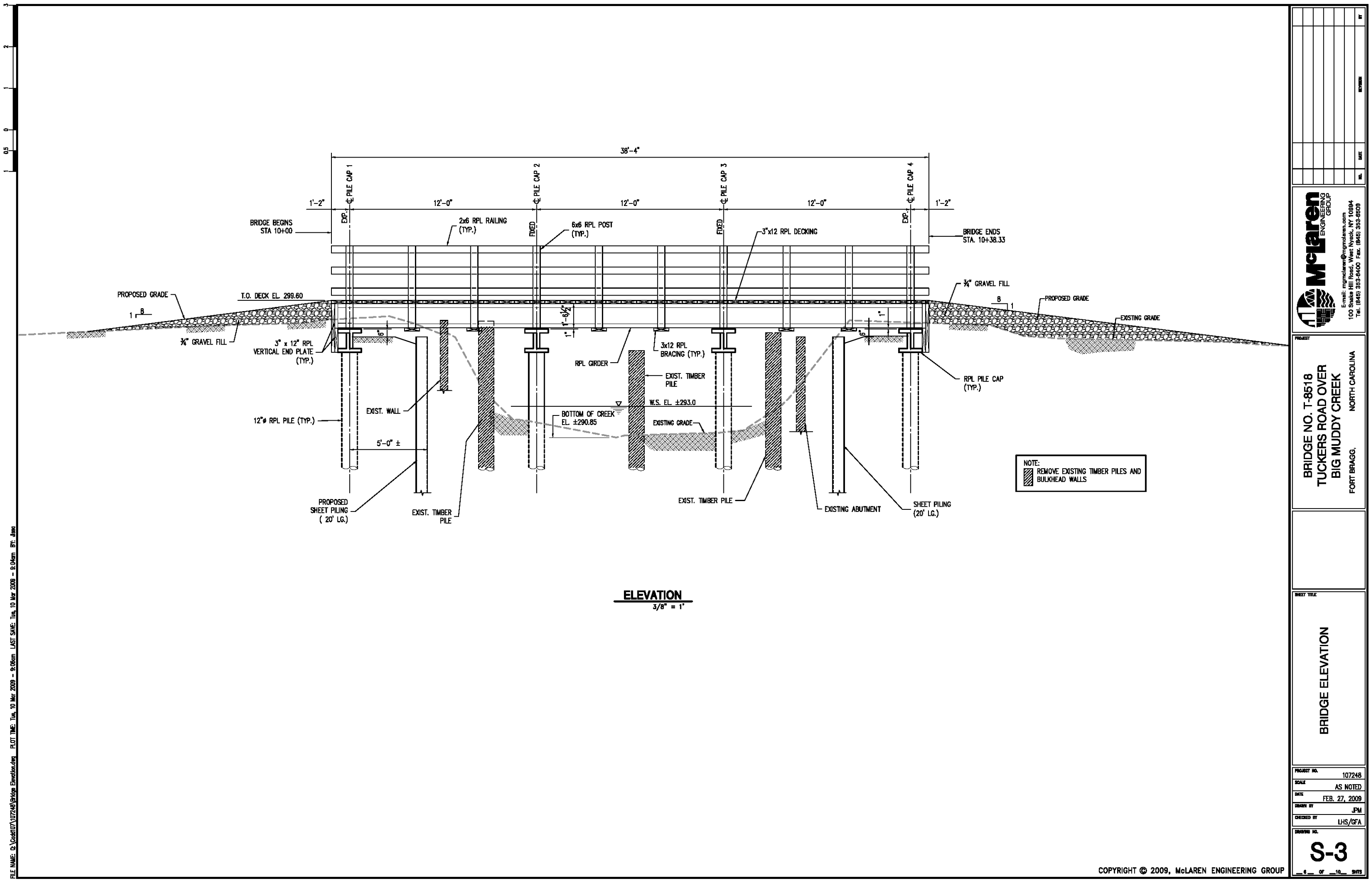


Figure A7. Sheet S-4, sections and details for Bridge T-8518 (1 of 3).

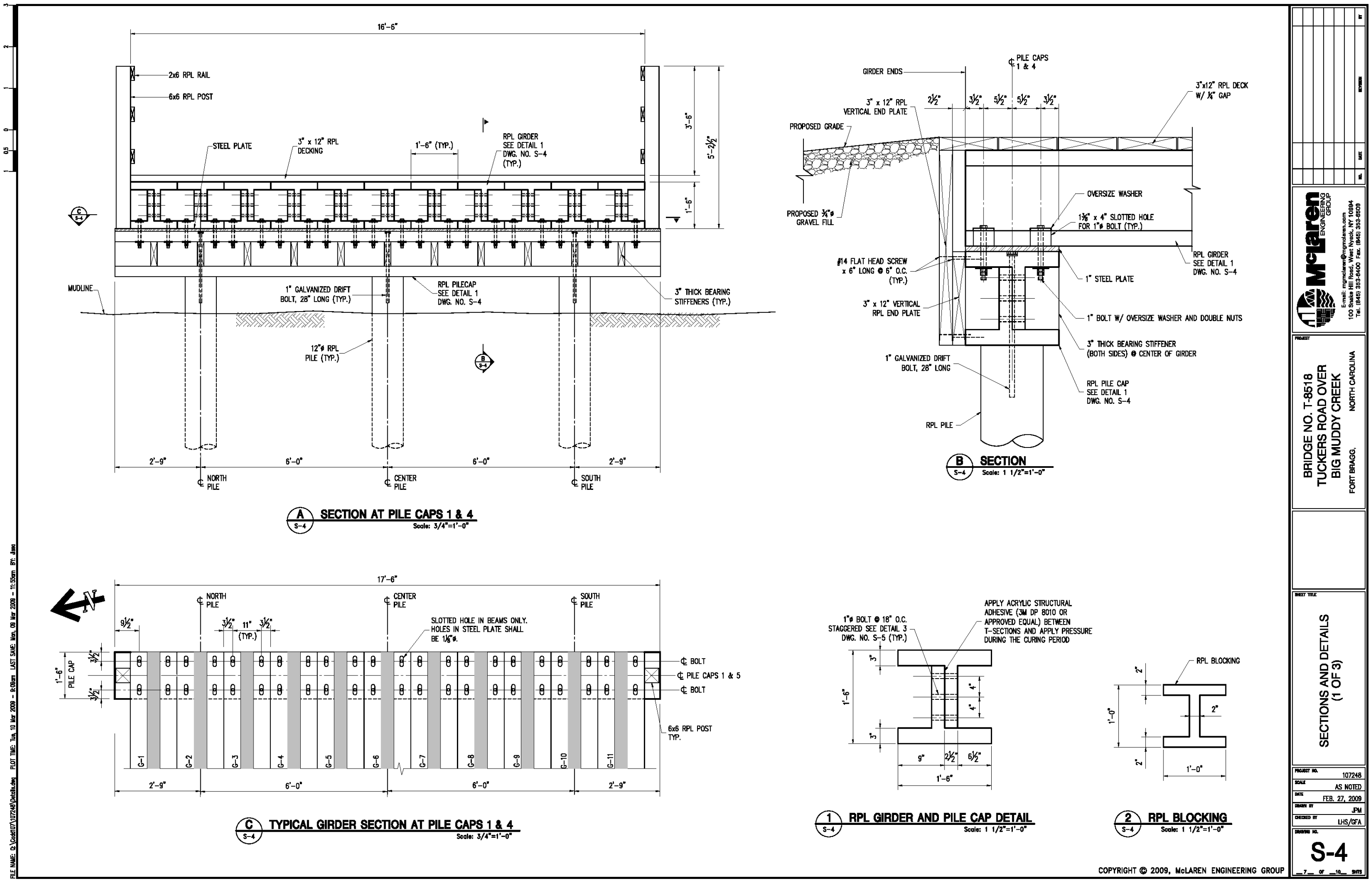


Figure A8. Sheet S-5, sections and details for Bridge T-8518 (2 of 3).

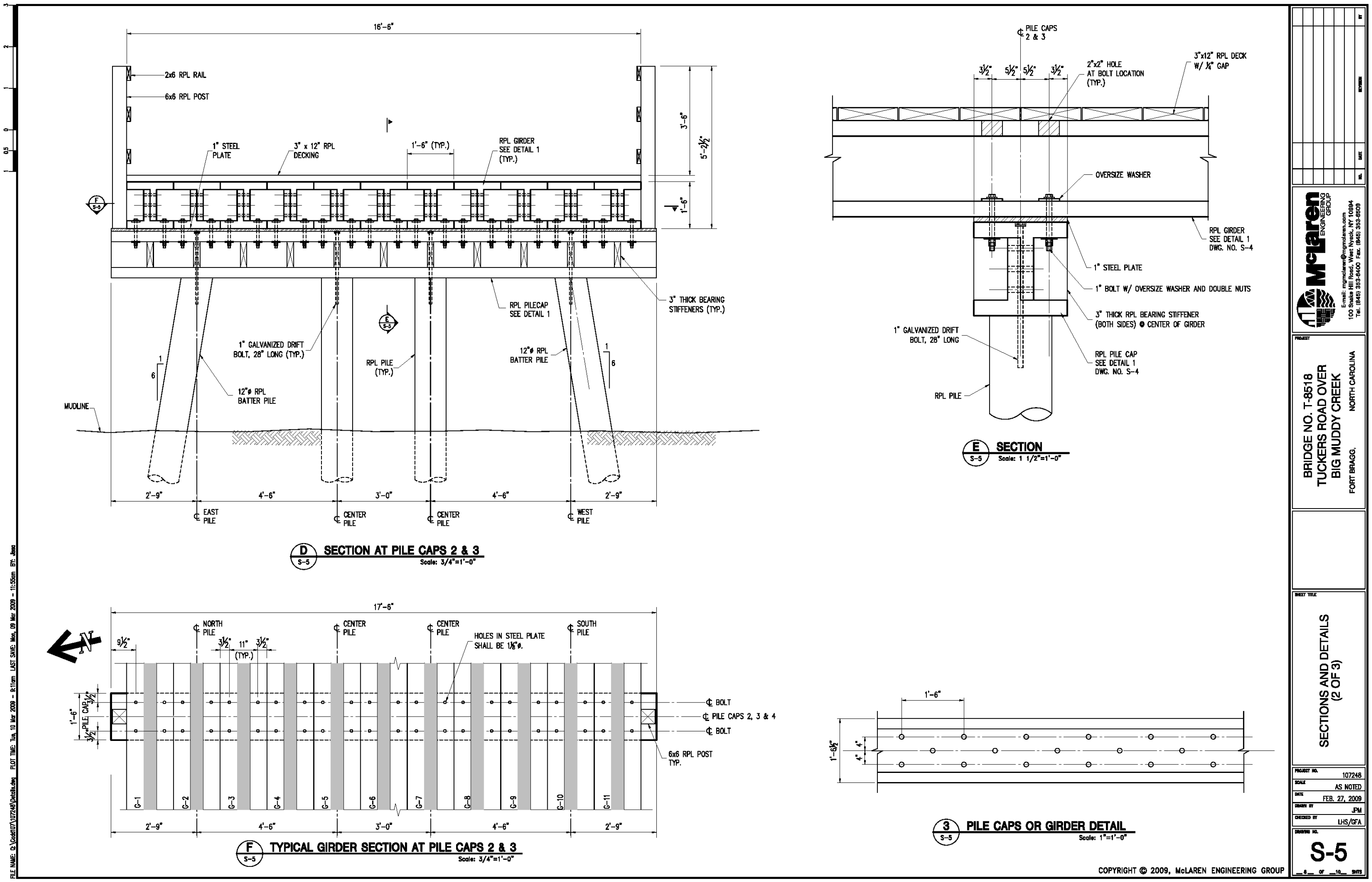


Figure A9. Sheet S-6, sections and details for Bridge T-8518 (3 of 3).

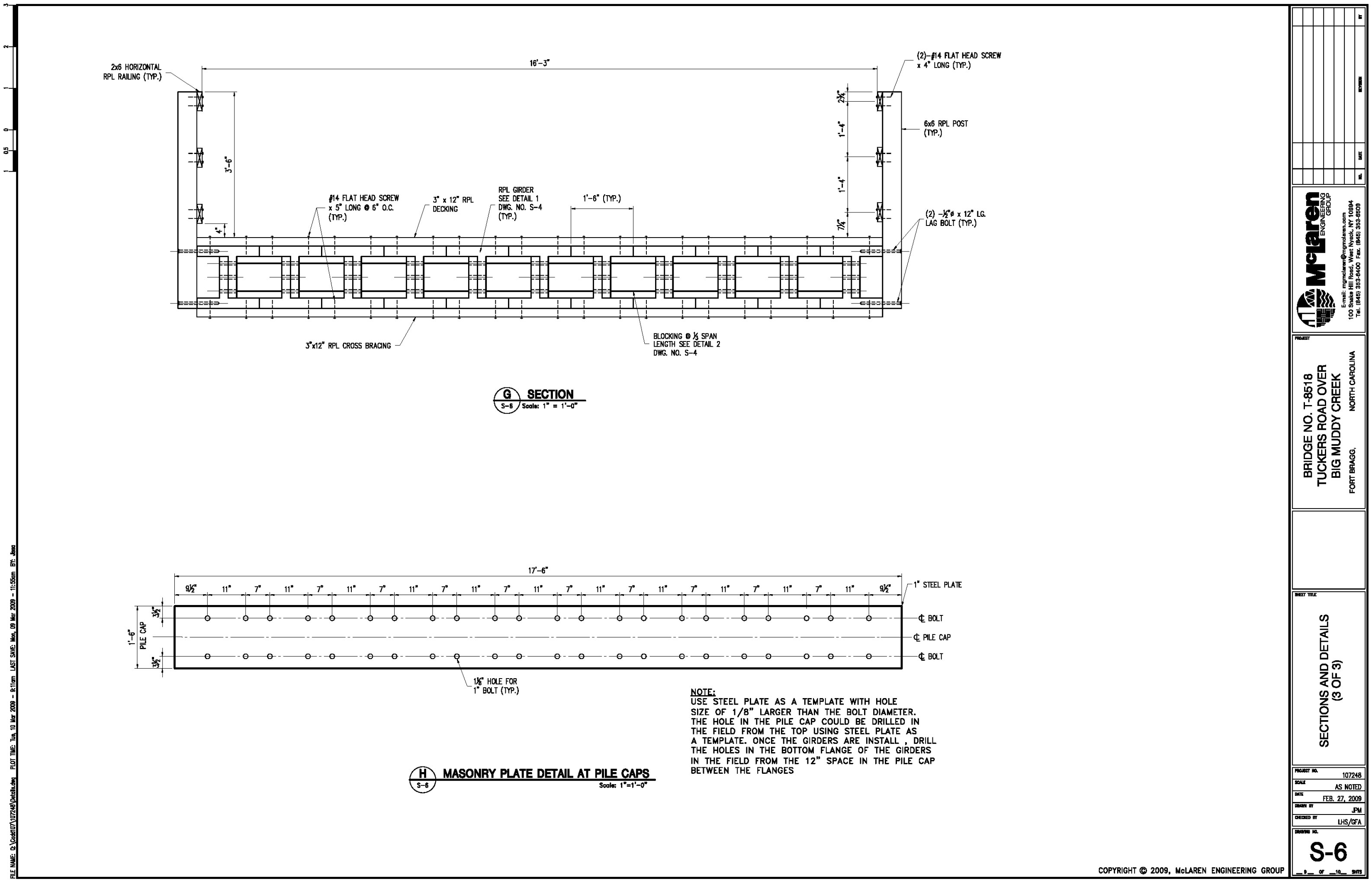


Figure A10. Sheet ER-1, erosion control notes and detail for Bridge T-8518.

Erosion Control Notes

1. ALL AREAS DISTURBED DURING CONSTRUCTION SHALL BE SEEDED AND MULCHED. SEED MIX, SOIL AMENDMENTS, AND PREPARATION SHOWN BELOW ARE RECOMMENDED, BUT ARE NOT REQUIRED AS LONG AS THE CONTRACTOR ESTABLISHES A SATISFACTORY STAND OF GRASS. A SATISFACTORY STAND OF GRASS IS DEFINED AS FOLLOWS:

   A STAND OF TURF IS CONSIDERED ACCEPTABLE WHEN THE NEW GROWING SPROUTS OF PERMANENT GRASS ARE VISIBLE AT THE SURFACE SHOWING NOT LESS THAN 40 SEEDLINGS OF PERMANENT GRASS AT LEAST 2 INCHES LONG IN EACH SQUARE FOOT, WHERE NO GAPS LARGER THAN 2 INCHES IN DIAMETER OCCUR ANYWHERE IN THE SEEDED AREA, AND WHERE THE TOTAL BARE SPOTS DO NOT EXCEED 2 PERCENT OF THE TOTAL SEEDED AREA. PERMANENT GRASS IS DEFINED AS COMMON BERMUDA.

2. SEEDING MAY BE EITHER BY HAND OR HYDROSEEDING.

3. RECOMMENDED PREPARATION FOR SEEDING AND MULCHING:

   A. AREA WILL BE TILLED TO 4" DEPTH

   B. APPLY LIME AT 70 POUNDS PER 1000 SQUARE FEET, OR 1.5 TONS PER ACRE

   C. APPLY 10-20-20 FERTILIZER AT A RATE OF 850 POUNDS PER ACRE OR 20 POUNDS PER 1000 SQUARE FEET. THE FERTILIZER SHOULD BE EITHER SLOW TIME RELEASE OR APPLIED IN TWO APPLICATIONS, HALF AT TIME OF PLANTING AND THE SECOND HALF AFTER PERMANENT SEED GERMINATES.

   D. THE LIME AND FERTILIZER WILL BE WORKED INTO THE TOP 2 TO 4 INCHES OF SOIL PRIOR TO SEEDING.

   E. PERMANENT SEED MIX AND RATE:

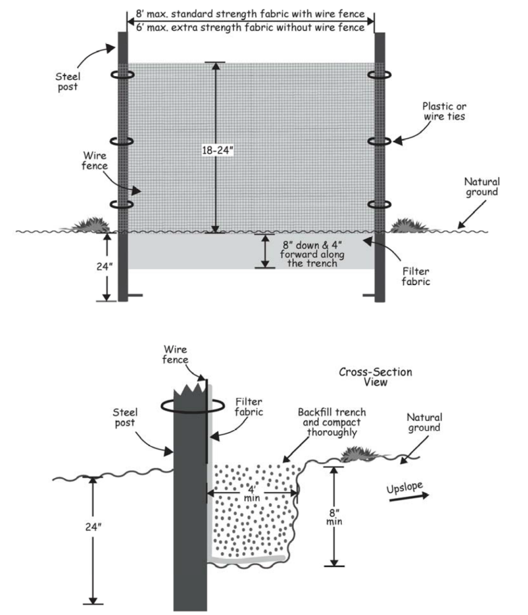
      "COOL SEASON": PLANTED BETWEEN 1 SEPTEMBER AND FEBRUARY 28
      50 POUNDS PER ACRE SOFT RED WINTER WHEAT. NO RYE GRASS.
      25 POUNDS PER ACRE COMMON BERMUDA (CYNODON DACTYLON), HULLED
      25 POUNDS PER ACRE COMMON BERMUDA (CYNODON DACTYLON), UNHULLED

      "WARM SEASON": PLANTED BETWEEN 1 MARCH AND 31 AUGUST
      50 POUNDS PER ACRE GERMAN (SETARIA ITALICA) , BROWN TOP (SETARIA ITALICA), OR FOX TAIL MILLET (BRACHIARIA RAMOSUM)
      50 POUNDS PER ACRE COMMON BERMUDA (CYNODON DACTYLON), HULLED

   F. STRAW MULCH: 4,000 POUNDS PER ACRE. THE GROUND SHOULD BE COMPLETELY COVERED WITH NO BARE SPOT LARGER THAN A QUARTER, THEN TACKED WITH EMULSIFIED ASPHALT. EMULSIFIED ASPHALT SHALL BE APPLIED AT A RATE HEAVY ENOUGH THAT THE ENTIRE AREA APPEARS BLACK IN COLOR.

4. IF REINFORCEMENT MATTING IS USED: HIGHLY RECOMMEND MESH OR OPENINGS ½ INCH OR LESS.

5. REMOVE SILT FENCE ON ACCEPTANCE OF PERMANENT SEEDING BY FORT BRAGG WATER MANAGEMENT BRANCH.



INSTALLATION DETAIL OF A SEDIMENT FENCE
N.T.S

McLaren ENGINEERING GROUP

BRIDGE NO. T-8518
TUCKERS ROAD OVER
BIG MUDDY CREEK
FORT BRAGG, NORTH CAROLINA

EROSION CONTROL
NOTES AND DETAIL

107245
AS NOTED
FEB. 27, 2009
JPM
LHS/GFA

ER-1

Figure A11. Sheet S-2, plan and general layout for Bridge T-8519, showing staggered girder design.

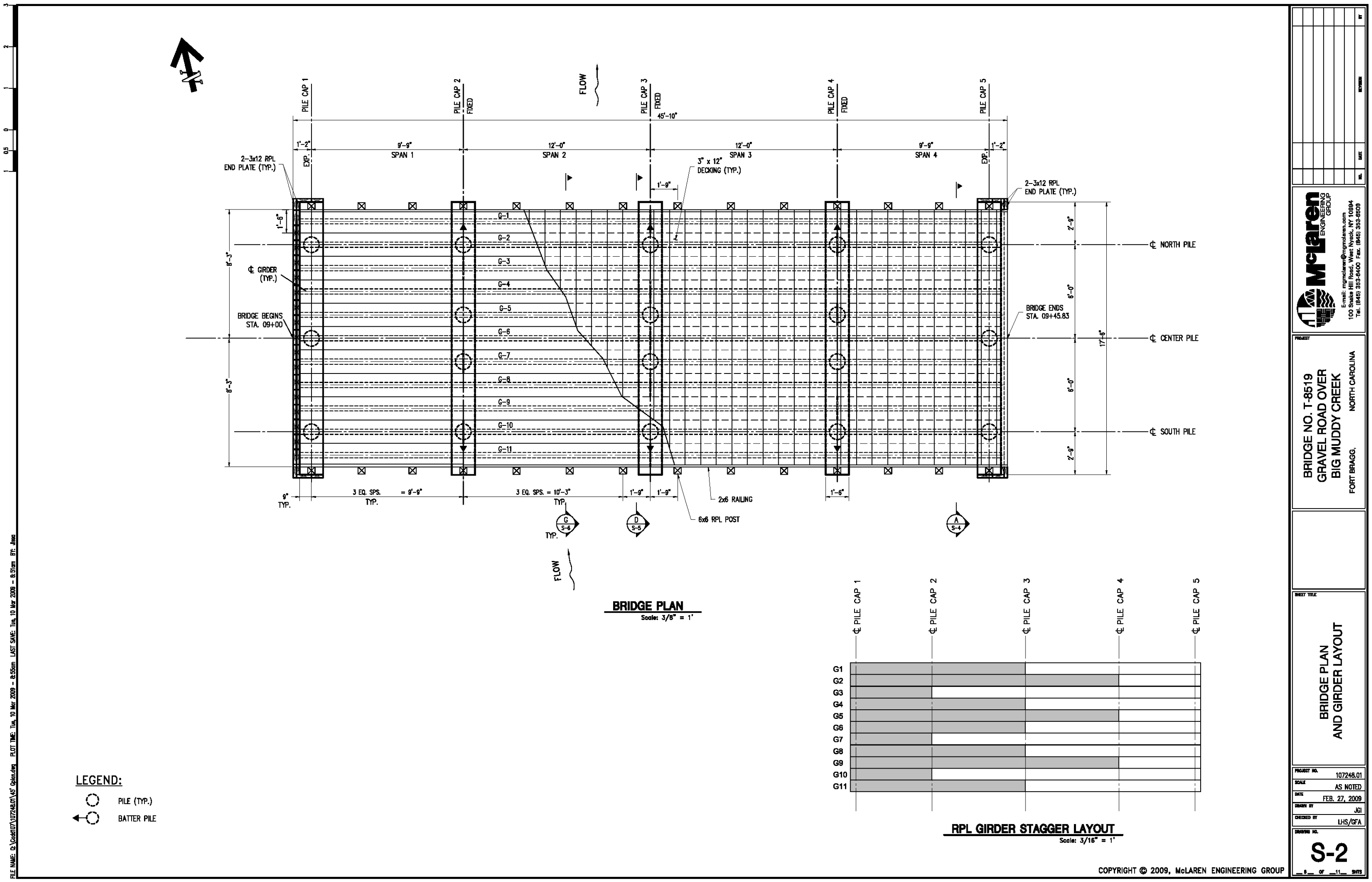


Figure A12. Sheet S-1, general plan for Bridge T-8520, showing alternative vinyl sheet piling.

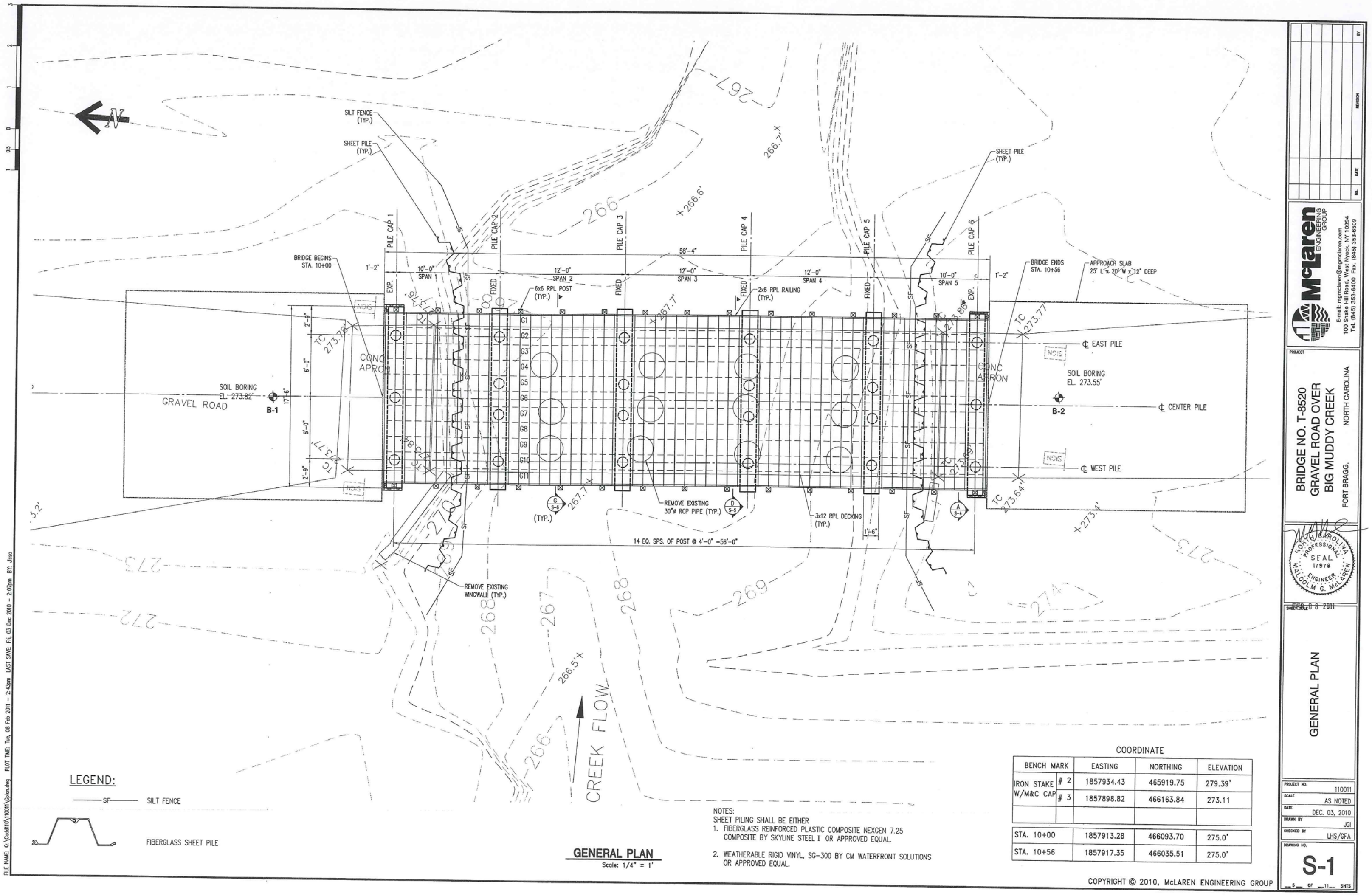


Figure A13. Sheet S-2, bridge plan and girder layout for Bridge T-8520, showing staggered girder design.

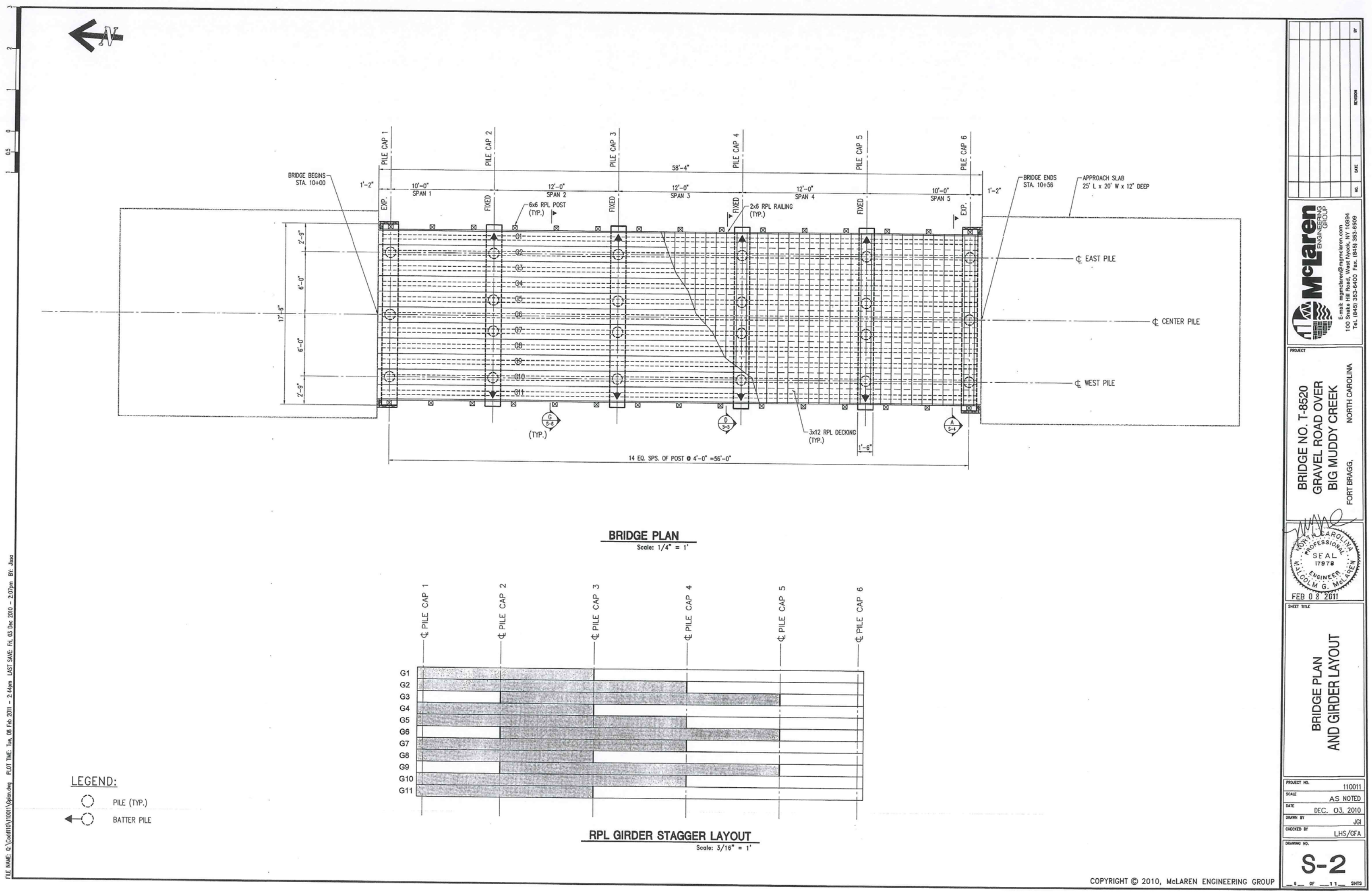
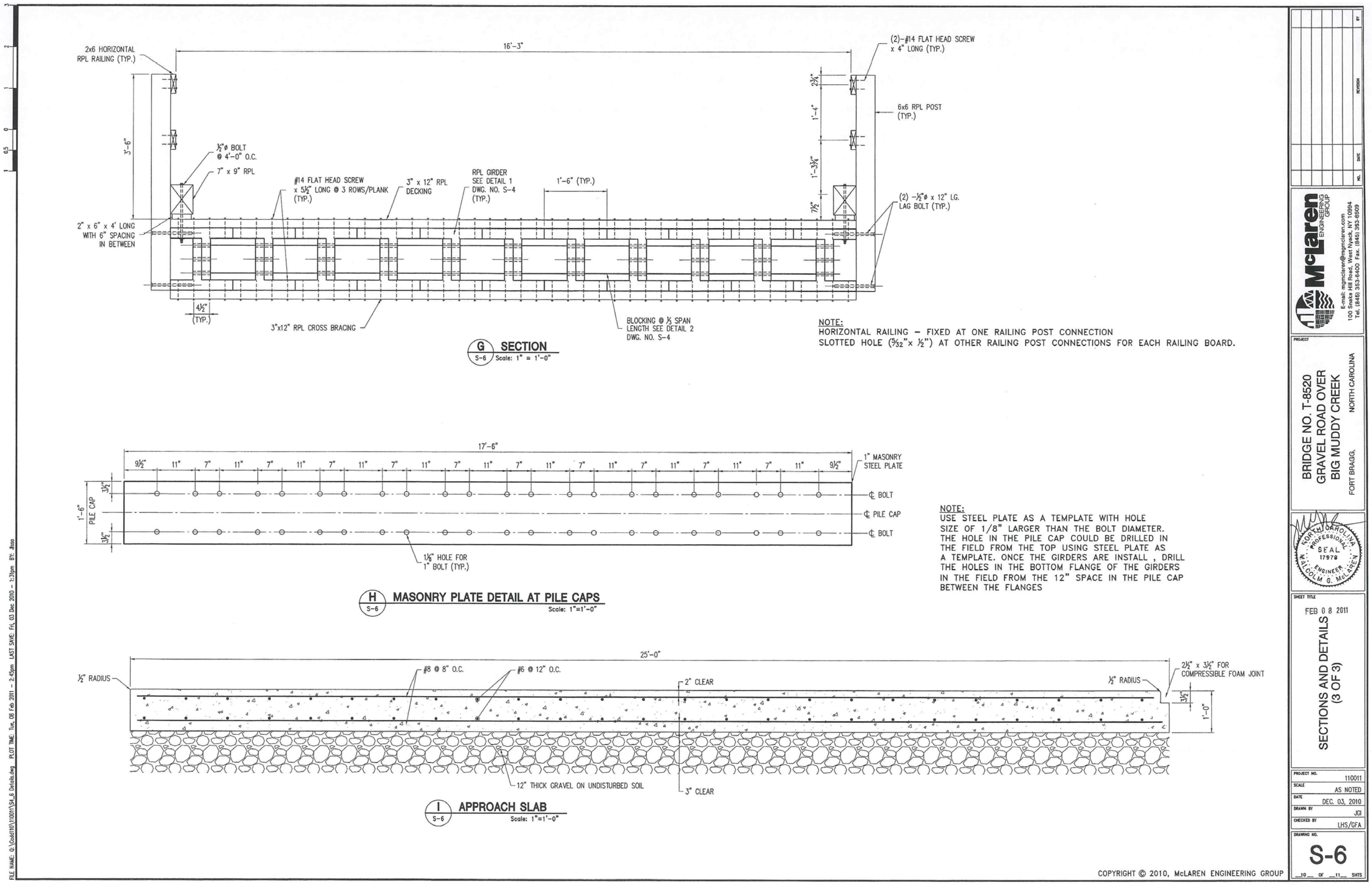


Figure A14. Sheet S-6 (3 of 3), sections and details for Bridge T-8520, showing changes in screw layout.



Appendix B: Construction and Inspection of Thermoplastic Composite Bridges[7]

B.1 Construction

Thermoplastic composite lumber expands and contracts to a greater extent with changes in temperature than does wood or steel. Design features were, therefore, incorporated to allow the plastic lumber bridge structure to move differentially relative to the steel members and the bridge abutments during such changes in temperature. These features included slotted connections between the plastic lumber joists and the steel girder to which they were attached to accommodate side-to-side movement, and a floating deck at the bridge abutments to accommodate end-to-end movement.

Thermoplastic composite materials can be drilled and cut with saws much like natural wood. However, due to the glass fiber reinforcement, carbide-tipped drills and saw blades are recommended.

B.2 Inspection

The following inspection checklist is will help assure a trouble-free structure with minimal maintenance in the long-term.

1. As described above, the thermoplastic composite lumber materials expands and contracts to a greater extent with changes in temperature than does wood or steel. It is imperative that the features designed to accommodate these movements are incorporated during construction and free to function. For example, components with slotted connections must be free to move with fasteners not over-tightened.

2. Cracking: During a visual inspection, the focus should be put on any appearance of cracks or splits. This includes cracking at and around the fastening points and at the apex of the beams. In the case of the 18 in. I-beams, it is not uncommon to find small gaps at the point of where the two bases of the T-beams meet (Figure D1). The T-beams are molded individually, then glued and bolted together to make the I-beam. These

[7] This material taken from Lampo et al. 2011.

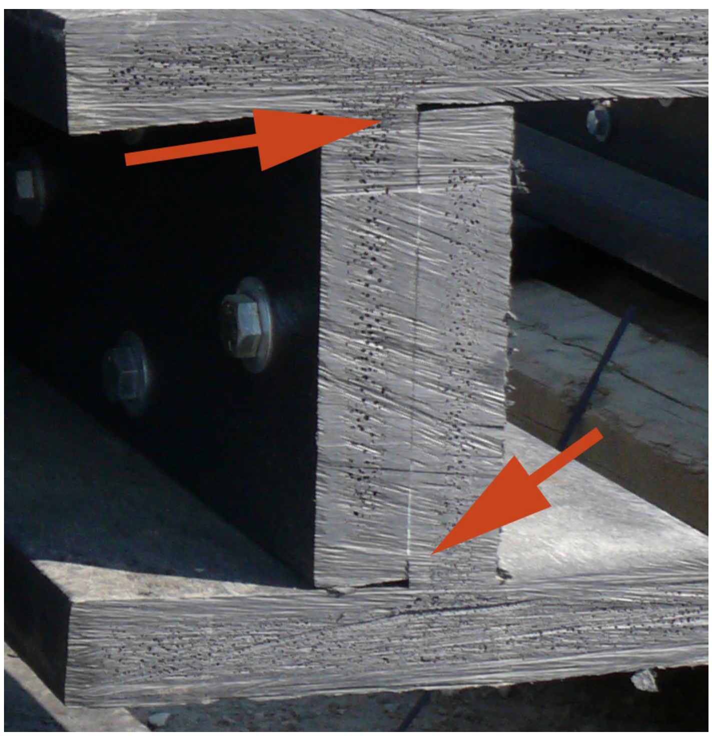
gaps represent the slight variation in the web depth of each T-beam during the manufacturing process. The presence of these gaps does not affect the structural capability of the I-beam. Although the appearance of cracking does not necessarily indicate mechanical failure, it should be photographed and appropriately documented for future monitoring.

3. Unusual or excessive movement of the piles and/or deck during vehicle crossing shall be documented.

4. Lateral shifting of the structure, with regard to abutment shifting shall be documented.

5. Determine that specified corrosion-resistant hardware and fasteners were used. Also verify that manufacturer's recommended torque specifications are maintaining initial settings.

Figure B1. Gaps at the point of contact between the two T-beams.



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
December 2017	Final Technical Report	

4. TITLE AND SUBTITLE
Demonstration of Thermoplastic Composite I-Beam Design Bridge at Camp Mackall, NC: Final Report on Projects FY08-16 and FY09-31

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT
ITTP

6. AUTHOR(S)
Richard G. Lampo, Thomas J. Nosker, George Nagle, Sarah B. Nemeth, Karl Palutke, and Lawrence Clark

5d. PROJECT NUMBER
FY08-16 and FY09-31

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
P.O. Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CERL TR-17-45

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of the Assistant Chief of Staff for Installation Management
Facilities Branch (DAIM-ODF)
2511 Jefferson Davis Highway
Arlington, VA 22202

10. SPONSOR/MONITOR'S ACRONYM(S)
OACSIM

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Bridges are essential to many military installations, especially in remote training areas. Like many of our nation's infrastructure bridges, U.S. Army bridges are in critical need of maintenance and repair due to the combination of wear and tear and material degradation, especially the hundreds of wood timber bridges. Repair or replacement represents a major cost to the Army that could be minimized by using cost-competitive, longer-lasting bridges. This effort determined that the innovative use of thermoplastic materials was successful in engineering and constructing a new bridge design that could safely carry the same or greater loads, be virtually maintenance-free, and be cost competitive on a first-cost basis when compared to wood timber bridges. Both the initial load testing and long-term monitoring as well as the life-cycle economic analysis for this project validated the beneficial use of the innovative thermoplastic materials and I-beam design. Moreover, this work is the first recorded effort to construct and demonstrate that a thermoplastic composite bridge of any type can bear the load of a 71-ton (64 Mg) Abrams tank. The results show that the design and materials achieved and surpassed their objectives, and they are recommended to be adopted on a widespread basis.

15. SUBJECT TERMS

Thermoplastic composites, Corrosion resistant materials, Structural engineering, Bridges, Materials--Dynamic testing, Camp Mackall (N.C.)

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified	UU	92	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18